Increasing the disaster resilience of remote communities through scenario co-creation

A thesis submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy in Disaster Risk and Resilience

by

Alistair J. Davies

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Department of Geological Sciences

University of Canterbury

2019

Abstract

Collaboration to enable participatory disaster impact reduction decision-making has become a political, policy and practice priority, for example, featuring in the 2015 Sendai Framework for Disaster Risk Reduction. However, divergent definitions of resilience, focussed either on preserving and restoring the built environment ("equilibrist resilience"), or on social change and adaptation ("evolutionary resilience"), have resulted in largely parallel bodies of literature and practice.

While all communities benefit from participating in disaster impact reduction efforts to some extent, this participation is essential for remote communities at risk of isolation due to disaster impacts. Remote communities increasingly rely on distributed infrastructure to provide essential services and are relied upon to implement disaster resilience. Moreover, if a remote community is isolated, community members will need to lead immediate response efforts in the absence of authorities, sometimes for considerable periods of time. Therefore, in practice, both the reduction of disruption to essential services and socio-cultural transformation are necessary to build the resilience of remote communities.

This doctoral project aims to address this gap in the field by developing and trialling an inclusive participatory, scenario-based approach to increase the resilience of a remote community to loss of essential services due to disaster damage to infrastructure, as an integrated component of wider initiatives to reduce inequities and effect social transformation. This aim was achieved by 1) identifying factors that affect the resilience of remote communities at risk of isolation from disasters triggered by natural hazards; 2) developing a participatory approach to integrate disaster impact reduction planning across stakeholder domains, to increase the resilience of remote communities at risk of isolation from disasters triggered by natural hazards; and 3) partnering with community members from Franz Josef, New Zealand, practitioners and policymakers to apply the participatory scenario-based approach.

This thesis addresses the fundamental divide between equilibrist and evolutionary resilience by demonstrating that it is possible to bridge the two disciplinary approaches. By developing and applying an "evolutionary" participatory governance approach to bring together community members, practitioners, policymakers and researchers, the participating stakeholder groups were all able to better understand the likely disruption, resulting from disaster damage to distributed infrastructure networks, and to make decisions to reduce both that disruption and the social consequences of it. Through this approach, Franz Josef community members, infrastructure providers and emergency managers have enhanced practical measures to improve readiness, reduction, response and recovery for major natural hazard events in the West Coast region of New Zealand. In doing so, the approach enabled an increase in the disaster resilience of a remote community.

Acknowledgements

This thesis would not have been possible without the generous support, encouragement, guidance and expertise of many friends, family and colleagues, near and far. Thank you, all.

Particular thanks are due to my supervision team: Assc. Prof. Thomas Wilson, Prof. Tim Davies, Dr. Sarah Beaven, Assc. Professor JC Gaillard, Dr. Matthew Hughes, and Dr. Liam Wotherspoon.

First, thank you to my senior supervisor, Tom. This PhD, including the move to New Zealand, has been a once-in-a-lifetime opportunity for which I am incredibly grateful for. I can honestly say that this PhD program and department have been the best in the world for me, and that is in no small part down to you. I have especially enjoyed working closely with *Project AF8*, the *Rural* and *Distributed Infrastructure* programmes, the Franz Josef community, practitioners and policymakers, as well as presenting my work locally, regionally, nationally and internationally. Many of these are beyond what many supervisors would consider part of a PhD or even trust a PhD student with, but your persistent hard work continually enabled my most-valued experiences. From day one you have trusted me with these opportunities, have been my biggest cheerleader and have always had my back. Whether that has been in the department, at conferences or more literally in the theatre, you really do go above and beyond for me and all of your students. Thank you.

Second, to my co-supervisor, Tim. I cannot imagine making it this far without you. Thank you for always, always being available for deep (and often tangential!) discussions, for being a voice of reason and for your unwavering confidence in me. Your sharp wit and formidable analysis have been a perilous joy to work with, and being a fellow (unrelated!) Brit has been a great comfort. Finally, your openness to new concepts and ability to not retire have been most impressive: thank you for sticking through with me!

Thank you also to my co-supervisors:

- Sarah, I feel very fortunate to have has you on my supervision team: you have been invaluable to my project. Your insight has opened up (almost too!) many new areas to grow the project, and you have always been incredibly generous in all of your guidance. I have also particularly valued your sharing of Maōri proverbs and culture, as well as your support of my musical ambitions! Thank you.
- JC, this project simply would not have been the same without you. I have been privileged to learn from the best in our participatory workshop efforts, and to teach the best a thing or two about darts! Thank you for finding time for me wherever you happened to be and for providing a highly-valued different perspective.
- Matthew, thank you for always being supportive and the biggest advocate of my work. Your help in every single workshop, guidance in stakeholder engagement and steadfast confidence

in myself and my project was invaluable, and it was always a great comfort to have my deputy cheerleader asking me tough questions at every conference! Thank you.

- Liam, you have persistently provided me with incredible opportunities to connect and collaborate with other researchers and practitioners, and to present my work. Your hard work connecting ongoing research has continually provided me with confidence in the direction of my project, and you have always been generous advocating for future opportunities for me. I can't thank you enough.

Most importantly, thank you to everyone in Franz Josef and all of the lifelines staff, emergency managers and policymakers who generously participated in this project. Without your enthusiasm and trust, this project simply would not have been possible. I hope you found the project as rewarding as I did.

I have been fortunate to receive financial support from the Earthquake Commission (EQC), the Resilience to Nature's Challenges National Science Challenge, QuakeCoRE and the University of Canterbury Department of Geological Sciences Mason Trust fund.

I have also made lifelong friends, many of whom are now colleagues, whilst studying in New Zealand. I cannot wait to continue making great things happen and socialising with you all. Special thanks to the CoUGARs and my old 412 officemates, Becs, Josh, Dan and Heather, who have really stuck by me through far too many rants and panics as I finished this thesis up!

A further thank you to my new colleagues at MCDEM, who have been incredibly supportive and understanding of my needs as I have been finishing this thesis while starting my new role.

Finally, thank you to my family, and especially to Mum and Dad. This thesis is dedicated to you. Thank you for inspiring me with your love of the natural world, encouraging me to work hard, and then not questioning where I wanted to go to pursue my passion, even when it was literally on the other side of the world. You have been a constant support and source of love. Here's to making you proud.

Contents

List of figures

List of tables

Co-authorship forms

Deputy Vice-Chancellor's Office

Postgraduate Research Office

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Co-Authorship Form

Chapter 2: The influence of participatory governance and distributed infrastructure dependence on the disaster resilience of remote communities: a systematic review

Prepared for submission.

The prepared manuscript was compiled and written by Alistair Davies, who also devised the research objectives, conducted the literature review and analysis, and interpreted the results. The concept of the manuscript was developed through discussions between Alistair Davies, Sarah Beaven, Thomas Wilson and Tim Davies. Sarah Beavan and Thomas Wilson contributed to refining and developing the manuscript. All co-authors reviewed draft versions of the manuscript before it was edited by Alistair Davies.

Certification by co-authors:

If there is more than one co-author, then a single co-author can sign on behalf of all.

The undersigned certifies that:

- The above statement correctly reflects the nature and extent of the PhD candidate's contribution to this co-authored work.
- In cases where the candidate was the lead author of the co-authored work, he or she wrote the text.

Name: Thomas M. Wilson

Signature:

Date: December 2018

Deputy Vice-Chancellor's Office

Postgraduate Research Office

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Co-Authorship Form

Chapter 3: Transport infrastructure performance and management in the South Island of New Zealand, during the first 100 days following the 2016 M_w 7.8 "Kaikōura" earthquake

Published by: Bulletin of the New Zealand Society for Earthquake Engineering, Vol. 50, No. 2, June 2017

The published manuscript was compiled and written by Alistair Davies., who also devised the research objectives and data analysis. Data collection was conducted in a collaboration between Alistair Davies, Vinod Sadashiva, Mohammad Aghababaei, Danielle Barnhill, Seosamh Costello, Briony Fanslow, Daniel Headifen, Matthew Hughes, Rudolph Kotze, Janelle Mackie, Prakash Ranjitkar, James Thompson, Daniel Troitino, Thomas Wilson, Stuart Woods and Liam Wotherspoon. The concept of the manuscript was developed through discussions between Alistair Davies, Vinod Sadashiva and Mohammad Aghababaei. Thomas Wilson and Liam Wotherspoon contributed to refining and developing the manuscript. All co-authors reviewed draft versions of the manuscript before it was edited for submission by Alistair Davies.

Certification by co-authors:

If there is more than one co-author, then a single co-author can sign on behalf of all.

The undersigned certifies that:

- The above statement correctly reflects the nature and extent of the PhD candidate's contribution to this co-authored work.
- In cases where the candidate was the lead author of the co-authored work, he or she wrote the text.

Name: Thomas M. Wilson

Signature:

Date: December 2018

Deputy Vice-Chancellor's Office

Postgraduate Research Office

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Co-Authorship Form

Chapter 4: The value of natural hazards scenario planning in increasing community disaster resilience: developing the AF8+ scenario for Franz Josef and the West Coast region, New Zealand

Prepared for submission.

The submitted manuscript was compiled and written by Alistair Davies, who also devised the research objectives, planned, co-ordinated and facilitated all workshops mentioned in this manuscript, and interpreted the results. The concept of the manuscript was developed through discussions between Alistair Davies, Thomas Wilson, Tim Davies and Sarah Beaven. The AF8+ scenario was adapted from the Project AF8 scenario with guidance from Tim Davies. JC Gaillard, Matthew Hughes, Thomas Wilson, Sarah Beavan and Liam Wotherspoon provided advice and support for workshop methodology, ethics and organisation. Thomas Wilson contributed to refining and developing the manuscript. All co-authors reviewed draft versions of the manuscript before it was edited for submission by Alistair Davies.

Certification by co-authors:

If there is more than one co-author, then a single co-author can sign on behalf of all.

The undersigned certifies that:

- The above statement correctly reflects the nature and extent of the PhD candidate's contribution to this co-authored work.
- In cases where the candidate was the lead author of the co-authored work, he or she wrote the text.

Name: Thomas M. Wilson

Signature:

Date: December 2018

Deputy Vice-Chancellor's Office

Postgraduate Research Office

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Co-Authorship Form

Chapter 5: Infrastructure failure propagations and recovery strategies from an Alpine Fault earthquake scenario: The value of feedback loops between integrated modelling and participatory processes for disaster impact reduction

Submitted to: Earthquake Spectra

The submitted manuscript was equally the joint work of Alistair Davies and Conrad Zorn. The integrated modelling methodology was developed by Conrad Zorn. The scenario-based participatory approach was developed by Alistair Davies. The concept of the manuscript, and the integration of the modelling methodology and scenario-based participatory approach, was jointly developed by Alistair Davies and Conrad Zorn. The submitted manuscript was equally written by Alistair Davies (50%) and Conrad Zorn (50%). Thomas Wilson and Liam Wotherspoon contributed to refining and developing the manuscript. Tim Davies and Sarah Beaven contributed to refining and developing the research objectives. Matthew Hughes provided support for workshop organisation. All co-authors reviewed draft versions of the manuscript before it was edited for submission by Alistair Davies.

Certification by co-authors:

If there is more than one co-author, then a single co-author can sign on behalf of all.

The undersigned certifies that:

- The above statement correctly reflects the nature and extent of the PhD candidate's contribution to this co-authored work.
- In cases where the candidate was the lead author of the co-authored work, he or she wrote the text.

Name: Thomas M. Wilson

Signature:

Date: December 2018

Deputy Vice-Chancellor's Office

Postgraduate Research Office

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Co-Authorship Form

Appendix A: Assessment of multi-hazard exposure on regional infrastructure in the West Coast region, New Zealand

Published by: 1st International Conference on Natural Hazards & Infrastructure

The published conference manuscript was compiled and written by Alistair Davies, who also devised the research objectives, conducted the data analysis, and interpreted the results. The concept of the manuscript was developed through discussions between Alistair Davies, Tim Davies and Thomas Wilson. Thomas Robinson and Theo Kritikos provided data and assisted with data analysis methodology development. All co-authors reviewed draft versions of the manuscript before it was edited by Alistair Davies.

Certification by co-authors:

If there is more than one co-author, then a single co-author can sign on behalf of all.

The undersigned certifies that:

- The above statement correctly reflects the nature and extent of the PhD candidate's contribution to this co-authored work.
- In cases where the candidate was the lead author of the co-authored work, he or she wrote the text.

Name: Thomas M. Wilson

Signature:

Date: December 2018

Deputy Vice-Chancellor's Office

Postgraduate Research Office

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Co-Authorship Form

Appendix B: Increasing communities' resilience to disasters: An impact-based approach

Published by: International Journal of Disaster Risk Reduction

The submitted manuscript was compiled and written by Tim Davies, lead author of the manuscript. The concept of the manuscript was developed through discussions between Tim Davies and Alistair Davies. Alistair Davies contributed to refining and developing the manuscript.

Certification by co-authors:

If there is more than one co-author, then a single co-author can sign on behalf of all.

The undersigned certifies that:

- The above statement correctly reflects the nature and extent of the PhD candidate's contribution to this co-authored work.
- In cases where the candidate was the lead author of the co-authored work, he or she wrote the text.

Name: Thomas M. Wilson

Signature:

Date: December 2018

1. Introduction

1.1 A disaster resilience knowledge divide

The 2015-2030 Sendai Framework for Disaster Risk Reduction stresses the need to address social inequality to reduce exposure to disaster damage as a guiding principle: ‘Disaster risk reduction requires an all-of-society engagement and partnership. It also requires empowerment and inclusive, accessible and non discriminatory participation, paying special attention to people disproportionately affected by disasters, especially the poorest. A gender, age, disability and cultural perspective should be integrated in all policies and practices, and women and youth leadership should be promoted. In this context, special attention should be paid to the improvement of organized voluntary work of citizens’ (UNISDR, 2015b, 19d, p. 13).

This emphasis on the use of inclusion, participation and empowerment to address social inequities is consistent with what White and O’Hare (2014) have recently identified as the “evolutionary” understanding of resilience that is common in academic planning and social science contexts. The understanding that disasters first and foremost affect the people local to the disaster event has contributed to growing recognition of the need to involve community members in disaster resilience decision-making that is likely to affect them (Gaillard & Mercer, 2013). “Evolutionary resilience” is consequently focussed on the use of adaption and transformation to address the social factors that increase the vulnerability of communities, and to respond to diverse and rapidly changing social, political and natural environments (White & O'Hare, 2014). However, White and O'Hare (2014) have found that, in practice, this transformative potential is largely neutralised by the tendency in engineering, policy and other institutional spheres to use what they term “equilibrist” definitions of “resilience”. Where “evolutionary resilience” emphasises social change and adaptation, “equilibrist resilience” is focussed on preserving and restoring the built environment, typically as part of “return to normal” approaches, in which top-down, techno-rational approaches are used to deliver universally applicable solutions (White & O'Hare, 2014). For example, this “equilibrist” emphasis is evident in the Sendai Framework global target concerned with infrastructure resilience, which aims to ‘[s]ubstantially reduce disaster damage to critical infrastructure and disruption of basic services’ (UNISDR, 2015b, 18d, p. 12), and the associated priority for action, ‘Build Back Better’, which includes promoting ‘the resilience of new and existing critical infrastructure… to ensure that they remain safe, effective and operational during and after disasters in order to provide life-saving and essential services’ (UNISDR, 2015b, 33c, p. 21).

The tendency to use the term resilience in one of two, opposed senses, identified by White and O'Hare (2014), can have an unhelpfully polarising effect on the conversation about disaster resilience. The benefits of inclusive, participatory approaches have been well established, and include: more empowerment of community members; more benefits to community members; reduced conflict; increased trust in government decision-making; greater perceptions that decisions are fair; better quality decisions; and better identification of disaster risk (Section 2.2.3) (see Reed, 2008, for a summary). It has also been well established that to function effectively, most communities are becoming increasingly reliant on essential services such as transport, electricity supply, and telecommunications (including calls, texts and data) (Gardner, 2015). Damage to the infrastructure networks that provide these essential services, including that caused by natural hazards (e.g. landslides, flooding, earthquakes), can result in the partial and sometimes complete loss of a given community's essential services for considerable periods of time, at significant social as well as economic cost.

In practice, both socio-cultural transformation and the reduction of disruption to essential services are necessary to build the resilience of remote communities. However, to date, the divide identified by White and O'Hare (2014) has resulted in largely parallel bodies of literature (and practice) focussed either on the relationship between infrastructure and community resilience, or on the use of participatory governance to build social resilience at the community level, with very little research combining these findings into more integrated, holistic resilience building approaches.

This thesis has adopted the United Nations International Strategy for Disaster Reduction (UNISDR, 2017) definition of "resilience", since it clearly attempts to combine both evolutionary and equilibrist emphases: 'the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.' Note, however, that restoring 'essential basic structures and functions' does not mean replicating pre-disaster structures and functions exactly, since these may have been the cause of vulnerability (Appendix B).

There is a clear need for more integrated approaches to building resilience in practice, in which inclusive, participatory approaches are used at the community level to reduce the exposure of communities to essential service disruption due to disaster damage to infrastructure, as part of wider initiatives to reduce inequities and effect social transformation (e.g. Paton & Johnston, 2017). This is particularly important for remote communities.

1.2 Remote communities and disaster resilience

Although specific definitions vary, most countries use (small) size and (large) distance from essential services (e.g. hospitals) and urban centres (geographic remoteness) when categorising the 'remoteness' of regions and communities (e.g. Fiji Bureau of Statistics, n.d.; SARRAH, n.d.; Statistics Canada, n.d.; Stats NZ, n.d.). The term "community" is often used to denote a group of people living or working in a geographic location, and particularly those who are involved to at least some extent in government or other administrative decision-making affecting the relevant location, as exemplified by all the articles identified in this review. This use of the term "community" has been critiqued on the grounds that it implies a homogeneity that may not exist in practice, meaning that so-called "community based" initiatives that assume this homogeneity risk overlooking existing conflicts and entrenching existing, inequitable power relations (e.g. Cannon, 2014). Acknowledging the validity of this critique, and the essentially heterogenous reality of any population, the term "community" is used in this thesis to refer to the varied group of people who are (or are likely to be) exposed to the same disaster impacts through social, spatial and/or immediate economic links (Appendix B).

Remote communities increasingly rely on essential services, such as electricity, transport, and telecommunications (including calls, texts and data), provided by distributed infrastructure, making them particularly vulnerable to disasters (Gardner, 2015). The rapid expansion of distributed infrastructure (particularly transportation and telecommunication networks) has provided many remote locations with new development opportunities, such as tourism and modern agriculture (Gardner, 2015). At the same time, the management and provision of essential services have become increasingly centralised (Gardner, 2015). Both new development opportunities and increasing centralisation have increased the dependence of many remote communities on distributed infrastructure to provide essential services. This makes the resilience of distributed infrastructure to the impacts of natural hazards an important component of the resilience of many remote communities because a natural hazard event can cause distributed infrastructure damage which disrupts a dependent community, even if the community is not otherwise impacted by the event (Section 1.3). Increasing dependence on distributed infrastructure for the provision of essential services to remote communities also means that loss of essential services can cause much greater impacts.

Remote communities are also particularly in need of participatory resilience-building initiatives. Involvement in disaster management decision-making is necessary because, if isolated, community members will need to lead immediate response efforts in the absence of authorities, sometimes for considerable periods of time (Gardner, 2015; Orchiston, 2013). While consistent with the benefits of participation established in wider participatory governance literature (Section 1.4), this need is more acute in remote communities, at least in part due to the growing centralisation of essential services. In some communities, the need for cost efficiency in local government has meant that responsibility increasingly falls to community members and organisations, so that community members are relied upon for, and essential to, much of the success of disaster management (Remling & Veitayaki, 2016).

1.3 Distributed infrastructure resilience

Communities require critical services, such as electricity, transport, telecommunications (including calls, texts and data), water and sewerage to be able to function. Infrastructure networks, such as electricity lines, roads, and fibre optic cables, normally provide these services, but can be impacted by both damage and network disruption. Where there is low or no infrastructure redundancy, damage to only one part of an infrastructure network can result in substantial reductions to the service level being provided, and/or can make it impossible for undamaged parts of the network to function. For example, a landslide blocking a road can require large detours or result in isolation of the remainder of the road network. Moreover, infrastructure networks are usually highly interdependent, meaning that impact on one service is likely to have cascading negative consequences for other infrastructure networks, reducing the service level provided by other networks and increasing the time required to repair them (Buldyrev et al., 2010). Therefore, damage to infrastructure and consequent network disruption, often caused by natural hazards (such as earthquakes, flooding, and volcanic eruptions), can result in the partial and sometimes complete loss of a given community's essential services for considerable periods of time, at substantial societal and economic cost.

Accordingly, the modelling of infrastructure networks' asset failure, interdependencies, and recovery is an ongoing focus of disaster management research worldwide (Hickford et al., 2018; Ouyang, 2014). However, while engineers have long worked to decrease the physical vulnerability of infrastructure assets, there is growing recognition of the need to address the societal implications of infrastructure damage and disruption in contemporary infrastructure studies (Chang, 2014) and in the 2015-2030 Sendai Framework for Disaster Risk Reduction (UNISDR, 2015b). Although maintaining distributed infrastructure networks remains crucial, earlier emphasis on "asset-driven" resilience has shifted towards ensuring the provision of services. For example, in New Zealand, ensuring that households and businesses are accessible is now prioritised over ensuring that the road network is not damaged (Chapter 3; National Infrastructure Unit, 2015).

This shift in focus to the societal implications of essential services outages has necessarily led to more interdisciplinary research (Chang, 2014; Grabowski et al., 2017; Hansman et al., 2006; McDaniels et al., 2015; Paton & Johnston, 2017; Pescaroli & Alexander, 2016) and policy priorities (ODI & The World Bank, 2015; UNISDR, 2015a; World Bank, 2014). There has been particular success from collaboration between infrastructure operators, both in response and pre-disaster mitigation. Again using an example from New Zealand, an interdisciplinary collaboration in the late 1990's between local and regional government, private infrastructure providers and university researchers resulted in mitigation to Christchurch city's power distribution network which progressed systematically each year and, in total, cost NZ$6 million (Centre for Advanced Engineering, 1997; Fenwick, 2012). When the 2010-2011 Canterbury Earthquake Sequence impacted the city, the mitigation programme was later assessed to have saved NZ$60-65 million in direct asset replacement costs alone, and it was noted that 'the damage would have been greater and the response slower if the steps recommended in… preparatory work… had not been taken' (Fenwick, 2012, p. ii; Giovinazzi et al., 2011). Interdisciplinary research is expected to continue to increase into the future as studies build on research and collaborations concerning multi-hazard implications for service delivery (Centre for Advanced Engineering, 1997; Giovinazzi et al., 2011; IEM, 2013; Zorn & Shamseldin, 2015), the economic implications of essential services outages (Cavallo & Noy, 2009; Chang et al., 2007; Deligne et al., 2015; Fenwick, 2012; Robinson et al., 2015), and the effects of essential service outages on community responses to disasters (Bressler et al., 2012; Cauffman, 2015; Jones & Benthien, 2011; Orchiston et al., 2018; Zorn et al., 2018). However, despite this trend, to date there is very little research that combines efforts to increase distributed infrastructure resilience and participatory efforts to increase the resilience of communities.

1.4 Participatory governance

Increasingly, approaches to increase resilience by direct community involvement are grouped together under the term "participatory governance", which has been defined as the direct involvement of community stakeholders in administrative decision-making and management processes, where a "stakeholder" is a person or organisation affected by the decision-making process and outcome (Aoki, 2018; Reed, 2008; Yang & Pandey, 2011). However, participatory governance involves substantial time and effort, and all stakeholders have limited time, resources and interest, restricting their capacity to participate in or facilitate additional activities (Reed et al., 2013). For example, existing commitments such as work and family can limit community members' abilities to participate, and limited time and resources can similarly discourage project leaders from facilitating intensive participation (Reed et al., 2013). Further, while community members are often consulted as part of disaster impact reduction efforts, they are very rarely involved in collaborative decision-making, particularly where infrastructure resilience is concerned (Aoki, 2018; Broad et al., 2007; Cooke & Kothari, 2001).

This thesis develops and applies an inclusive participatory approach in a collaboration between community members in Franz Josef, New Zealand, infrastructure providers, emergency managers, local government policymakers and researchers. The approach uses a scenario as a boundary object, and aims to enable an increase in the disaster resilience of remote communities through both decreased essential services disruption from increased infrastructure disaster resilience, and enhanced social resilience through more informed and collaborative decision-making. The intent of this thesis is to start to provide theoretical underpinning to this practical need. The aims of this thesis are detailed in Section 1.6.

Various typologies have been proposed to broadly categorise scenario planning projects (Bishop et al., 2007). Börjeson et al. (2006) identify three scenario planning categories, according to whether they address probable, possible or preferable futures: predictive scenarios address "what will happen?"; explorative scenarios address "what can happen?"; and normative scenarios address "how can a specific target be reached?" (Bishop et al., 2007). In scenario planning for natural hazards, normative foresight studies which have a pre-determined outcome and explore alternative paths used to reach this outcome, are less common (Wodak & Neale, 2015). This disparity is not the focus of this project, but given the need for communities to decide their own futures, foresight studies where community members can describe their collective desired future and consider how to achieve this are a notable, currently underutilised, alternative for participatory governance.

Further, while social power relations and dynamics are critical to community disaster preparedness (Blake et al., 2017) and indeed any participatory work, they are not the focus of this thesis. Research into this topic was instead conducted in parallel, within a closely aligned research project (Hore et al., in review).

1.5 Case study context: Franz Josef, New Zealand

Franz Josef/Waiau is a remote community located in Westland district, within the West Coast region of the South Island of New Zealand (Figure 1). The town is famous for its temperate maritime glacier, which descends from the Southern Alps to around 400 metres above sea level. Kā Roimata o Hine Hukatere, later also named Franz Josef Glacier, was first shown to Europeans by Māori in the mid-19th Century, and a settlement has existed for the purposes of showing the glacier to tourists since the late-19th Century, when tracks and bridges were also built to provide access onto the glacier (Glacier Country Tourism Group, 2018b; Langridge et al., 2016). Subsequently, this settlement was named Franz Josef, after the glacier.

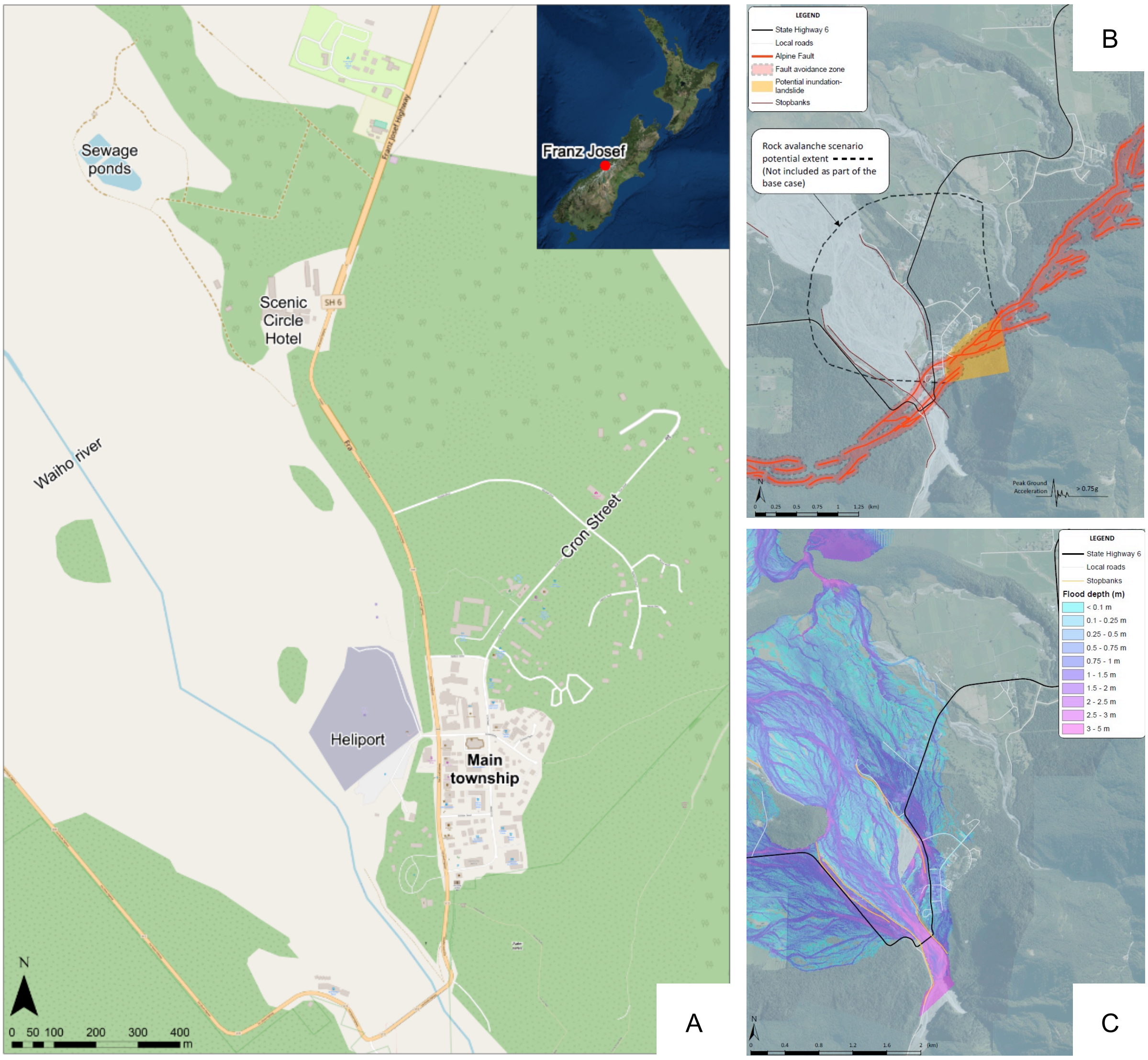

Figure 1. Maps of Franz Josef. A: Franz Josef, and its location within New Zealand.
B: Alpine Fault trace, FRAZ, rockfall & landslide zones (Tonkin + Taylor & EY, 2017, p. 26).
C: 100-year modelled river flood with 6m bed aggradation (Tonkin + Taylor & EY, 2017, p. 29).

Franz Josef's visitor numbers have risen sharply over the last decade, driven largely by a desire to see the glacier (Mitchell & Williams, 2018; Wilson et al., 2014). Franz Josef Glacier and the neighbouring Fox Glacier had 700,000 visitors in 2016, roughly 20% of total visitor arrivals in New

Zealand in the same year (Tonkin + Taylor & EY, 2017). For context, in 2016, international tourism expenditure contributed NZ$14.5 billion or 20.7% of New Zealand's total exports of goods and services (Stats NZ, 2016). This increase in visitors means that the number of tourists now dwarfs the number of residents in the town: approximately 6,000 people per day walked the Franz Josef Glacier track in peak season in 2018 (Morton, 2018), but the town has a resident population of approximately 450 people (Stats NZ, 2013).

Community members have identified that they need business expansion to cope with the current tourism "boom", increased tourism in winter to improve sustainability, and business diversification to reduce the town's dependence on the glacier, which is experiencing prolonged retreat, for the town to continue to prosper. However, while the community wants to increase investment in Franz Josef and expand the town, development is presently constrained as it has been established that the town is directly exposed to natural hazards that include earthquakes, floods, landslides, landslide-dambreak floods, severe storms (including ex-cyclones) and tornadoes (Westland District Council, 2002) (Figure 1). Franz Josef was developed at the foot of the Southern Alps, on the northern bank of the Waiho (Waiau) River, across what was later recognised as the fault trace of the Alpine Fault (Langridge & Beban, 2011; Langridge & Ries, 2009; McSaveney & Davies, 1998; Wellman, 1953). As a result, some buildings and critical infrastructure within the town are located directly on the fault trace (Figure 1). The Alpine Fault is an active fault considered capable of generating an M_w 8 earthquake (Stirling et al., 2012) and is late in its current seismic cycle, with an estimated ~30% probability of a major rupture in the next 50 years (Barnes et al., 2013; Cochran et al., 2017; De Pascale & Langridge, 2012; Stirling et al., 2012). The Waiho River poses a flood hazard due to considerable aggradation since the late-19th Century (Glacier Country Tourism Group, 2018a). Currently, the majority of the town is located below the level of the Waiho river bed and is completely reliant on stopbanks (river levees) for flood protection, which have exacerbated aggradation and continue to do so (Langridge et al., 2016; McSaveney & Davies, 1998). Development potential elsewhere in the vicinity is reduced due to several nearby secondary catchments (Docherty Creek, Tartare Stream, Stony Creek and Potters Creek) and its range-front location presenting a landslide risk (Langridge et al., 2016). While this landslide risk presently requires intensive investigation, it is potentially devastating (Barth, 2013; Langridge et al., 2016).

1.5.1 Franz Josef risk governance

Franz Josef is under the jurisdiction of Westland District Council (WDC), West Coast Regional Council (WCRC) and the New Zealand Government. The Resource Management Act (1991) tasks Councils with developing rules, objectives and policies to mitigate the effects from natural hazards. Specifically, regional councils are usually responsible for (amongst other responsibilities) regional policy statements, land use planning to avoid natural hazards, and ensuring sufficient development capacity for residential and business land to meet expected long-term demands of the region. WCRC fulfils this obligation through the West Coast Regional Policy Statement (West Coast Regional Council, 2000). District councils are usually responsible for (amongst other responsibilities) the effects of land use and ensuring sufficient development capacity for residential and business land to meet expected long-term demands of the district. WDC fulfils this obligation through rolling updates to the Westland District Plan (Westland District Council, 2002). Councils must consult with their communities when they prepare or review plans or regional policy statements, or consider a change or variation, but consultation approaches vary (MfE, 2018). In an evaluation of land use and emergency management plans for natural hazards in New Zealand, Saunders et al. (2015) find that information on the nature and location of natural hazards needs to be more accessible to the public, and more councils should implement a risk-based approach that engages with communities to determine levels of risk. However, whilst best practice, these are not required by legislation.

Management of Franz Josef's natural hazard risks has been highly contentious in the town (Day, 2003; Gough, 2001; Gough et al., 2001). Effective disaster impact reduction is challenging in Franz Josef not only due to the complex hazardscape, but also due to its specific social, economic, cultural, and political context (Fischer, 2000; Gough, 2000; Gough et al., 2001; Remling & Veitayaki, 2016). This already complicated situation has been compounded by previous risk management attempts, which have eroded trust between community members, emergency managers, and government (Section 4.2.1.1).

Despite this recent history, Franz Josef community members continue to demonstrate a keen desire to participate in disaster impact reduction efforts. In 2015, Franz Inc., Franz Josef's business collective, invited academics from the University of Canterbury and the University of Auckland to assist them to develop a planning strategy to increase the resilience of the town. Subsequently, a complex participatory disaster impact reduction process has developed. Several participatory groups aiming to increase the resilience of Franz Josef have developed, including the community members' and Universities' collaboration and a process led by the district and regional councils, both including a wide range of stakeholders. Up to the point of the activity described in this thesis, these processes have largely focussed on the direct impacts of flooding and earthquakes (Langridge et al., 2016; Tonkin + Taylor & EY, 2017).

1.5.2 New Zealand infrastructure resilience

Franz Josef's dependence on the West Coast region's linear distributed infrastructure for service delivery also increases the town's vulnerability (Chapter 2; Appendix A). The West Coast region has no network redundancy (except in towns) for over 400 kilometres, meaning Franz Josef is only accessible via ground transportation by a single road (State Highway 6) and is serviced by only one powerline and one telecommunications line (Figure 2) (National Infrastructure Unit, 2015; Tonkin + Taylor & EY, 2017; Willis, 2014).

With no redundancy, any disruption to any part of the distributed infrastructure networks can result in the partial and sometimes complete loss of a given community's essential services for considerable periods of time. Depending on the duration of the outage and various contextual factors, this can lead to potentially substantial social and economic impacts. The combination of low (or no) infrastructure redundancy and high hazard exposure (including earthquakes, landslides, landslide dam-break flooding, river flooding, rockfalls, severe storms, tornadoes and tsunami) in the West Coast region compounds the vulnerability of remote West Coast communities, including Franz Josef (Appendix A), and means that community members will likely be isolated in the event of a major disaster in the West Coast region. It has been identified by previous studies and the West Coast Civil Defence & Emergency Management (CDEM) Group that, when isolated, community members will likely be responsible for the immediate response efforts, including caring for stranded tourists who vastly outnumber residents and are unlikely to be prepared for a disaster (Orchiston, 2013; West Coast CDEM Group, 2016).

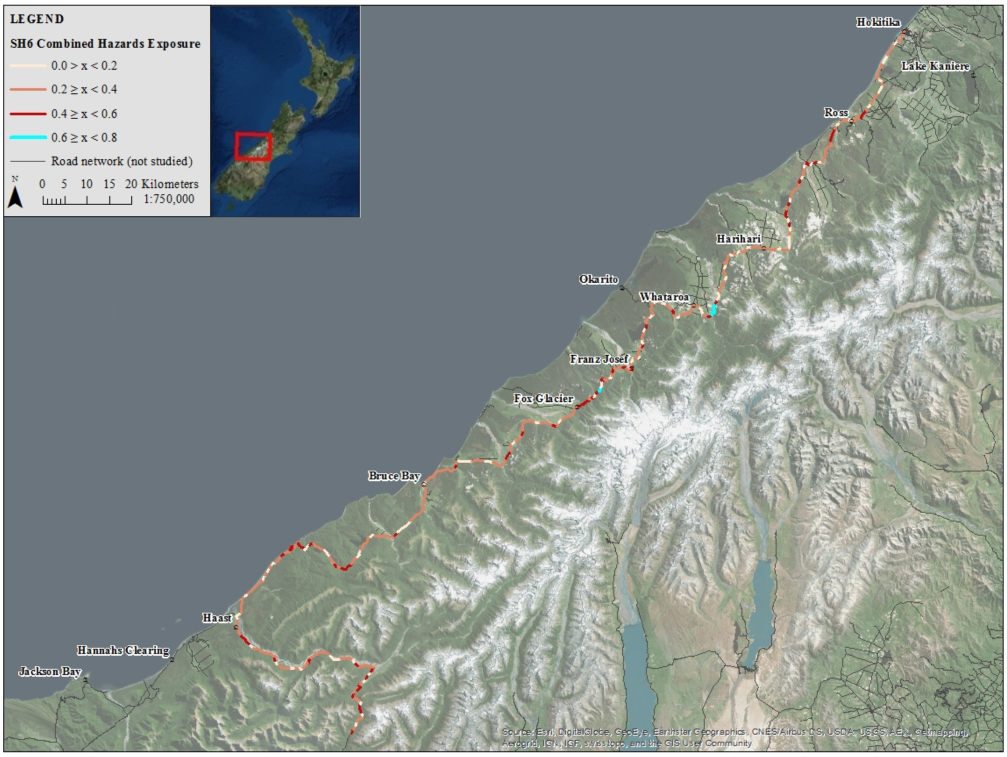

Figure 2. A map showing the South Island road network of New Zealand and the combined exposure of SH6 to earthquake rupture, landslide, debris flow and river flood (Appendix A, Figure 56).

Under the *Civil Defence Emergency Management Act 2002* (MCDEM, 2002), New Zealand government agencies at local, regional and national levels, infrastructure providers (often termed “lifeline utilities” or “lifelines”) and emergency services all have defined functions and responsibilities for disaster readiness, reduction, response, and recovery. Section 60 requires every lifeline utility to be ‘able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency’ (MCDEM, 2002, p. 40). Lifeline utilities must also establish planning and operational relationships with their regional Civil Defence & Emergency Management (CDEM) Group under the Act. In most regions, lifeline utilities predominantly fulfil their duties under the act by participating in regional lifelines groups, with national representation and coordination undertaken by the New Zealand Lifelines Council (est. 1999).

The West Coast Engineering Lifelines Group has undertaken a number of projects including natural hazards scenario planning and post-event debriefs to assess and improve the resilience of West Coast lifelines (e.g. McCahon et al., 2006,2017; West Coast Regional Council, 2014). These projects and other work fostered or contributed to by the Group and its members have developed valuable inter-personal and inter-corporate relationships and have improved the infrastructure resilience of the West Coast region. However, up to the point of the activity described in this thesis, community members have not been involved in these collaborative processes.

The remote character of Franz Josef and the town's dependence on distributed infrastructure means that there is an additional need for community participation, as community members in remote locations are relied upon to implement disaster resilience for cost efficiency (Remling & Veitayaki, 2016) and when isolated, community members lead immediate response efforts in the absence of input from authorities (Gardner, 2015; Orchiston, 2013) (Section 1.2). Therefore, this project aimed to enable collaboration between Franz Josef community members, infrastructure providers, emergency managers, local government decisionmakers and researchers. While the immediate objective was to increase the resilience of Franz Josef to essential services disruption and isolation, this process was also designed to build trust between the participants, to enable ongoing collaboration (Eiser et al., 2012).

1.6 Thesis aims

The aim of this thesis is to develop a participatory governance approach to increase the resilience of remote communities to natural hazards. This thesis then aims to implement this approach in a collaboration between community members from the town of Franz Josef, New Zealand, infrastructure and emergency management stakeholders (including local government officials), and university researchers. Many remote communities, including Franz Josef, are additionally vulnerable to natural hazards due to their dependence upon distributed infrastructure. It has also been established that remote communities particularly require participatory governance to build disaster resilience because they are often relied upon to implement resilience measures. However, to date, there is very little research that combines efforts to increase distributed infrastructure resilience and participatory efforts to increase the resilience of communities. Therefore, the main aims of this thesis are to:

1. **Identify factors that affect the resilience of remote communities at risk of isolation from disasters triggered by natural hazards.**
   Systematic review methodology and an impact assessment are used to achieve this aim. Systematic review methodology is used to bring together for the first time the research field concerned with the resilience of remote communities at risk of isolation following disasters triggered by natural hazards. Analysis and synthesis of this research field are used to increase understanding of the current focus of relevant research to inform further research and support relevant planning initiatives. An impact assessment of the 2016 M_w 7.8 "Kaikōura" earthquake in New Zealand, which isolated several remote communities, was also

conducted. Focussing on transport infrastructure, which was particularly disrupted in this event, the assessment highlighted lessons for distributed infrastructure resilience in relation to the resilience of remote communities. This study is particularly useful for remote communities in New Zealand, and again can be relevant for planning initiatives.

2. **Develop a participatory approach to integrate disaster impact reduction planning across stakeholder domains, to increase the resilience of remote communities at risk of isolation from disasters triggered by natural hazards.**
   Building on the findings of the literature review and "Kaikōura" earthquake assessment, this aim is achieved by developing an approach which combines efforts to increase distributed infrastructure resilience with participatory efforts to increase the resilience of communities. A scenario-based participatory approach is developed, utilising a scenario as a boundary object, to enable relevant, credible and legitimate decision-making from all stakeholder groups by combining and sequencing various (existing) participation methodologies.

3. **Partner with a remote community to apply the participatory approach, and demonstrate its capacity to integrate autonomous initiatives driven by any of the participating stakeholder groups into the approach.**
   The participatory approach was developed to increase the resilience of Franz Josef, New Zealand, and is applied in a "pre-disaster" collaboration between community members from the town, infrastructure and emergency management stakeholders, and university researchers. An Alpine Fault earthquake scenario (the AF8+ scenario) is used as the boundary object. Critically, it is demonstrated that the participatory approach allows stakeholders to understand other stakeholders' contributions, enabling them to immediately utilise these contributions to assess existing and implement new resilience measures in the "real world". The approach is then integrated with an autonomous integrated infrastructure modelling framework, demonstrating the ability of participating stakeholder groups to iteratively build on improvements in shared understanding.

1.7 Thesis structure and declarations

The subsequent content of this thesis forms four core chapters written to be published as journal papers. At the time of submitting this thesis, one manuscript has been published and one manuscript has been submitted to an academic journal for review.

- Chapter 2 contains a version of a manuscript prepared for submission and addresses Aim 1 of the thesis. Systematic review methodology is used to increase understanding of, and critically appraise, the current extent, range and focus of research concerned with the resilience of remote communities at risk of isolation following disasters triggered by natural hazards. This review brings together the research field for the first time to inform further research and support relevant planning initiatives. This review identifies that, to date, there is very little research that combines efforts to increase distributed infrastructure resilience and participatory efforts to increase the resilience of communities. This research gap is the focus of the subsequent three thesis chapters.

- Chapter 3 contains a version of a published manuscript and addresses Aim 1 of the thesis by investigating the impact of the 2016 M_w 7.8 "Kaikōura" earthquake in New Zealand. The chapter focusses on impacts to transport infrastructure, which was particularly disrupted in this event, and the resilience of remote communities, several of which were isolated by impacts to distributed transport infrastructure. The chapter evidences the advantage of the service-based (as opposed to asset-based) approach to infrastructure resilience adopted by New Zealand, but also evidences the vulnerability of remote communities in New Zealand to isolation from disasters triggered by natural hazards.
- Chapter 4 contains a version of a manuscript prepared for submission describing the development and application of a participatory approach to combine efforts to increase the resilience of Franz Josef, New Zealand, and increase the resilience of distributed infrastructure. Franz Josef is a remote community at risk of isolation from disasters triggered by natural hazards. A scenario-based participatory approach is developed, utilising the "AF8+" Alpine Fault magnitude 8 earthquake scenario as a boundary object, enabled by combining and sequencing various (existing) participation methodologies. The chapter successfully fulfils Aim 2, and also addresses Aim 3 of the thesis.
- The final chapter of this thesis, Chapter 5, contains a version of a submitted manuscript which addresses Aim 3 of the thesis by demonstrating the ability of participating stakeholder groups to successfully integrate autonomous initiatives into the approach. The modelling of infrastructure networks' asset failure, interdependencies and recovery are ongoing foci of disaster management research worldwide, but these models are not well integrated and rarely incorporate community knowledge. These research gaps are addressed by integrating an infrastructure modelling framework into the Franz Josef participatory approach detailed in Chapter 4.
- The final chapter of this thesis, Chapter 6, summarises the key findings in relation to the original thesis aims. Chapter 6 also outlines recommendations for future work, which are largely derived from the recent contributions to the discipline covered in this thesis.

The content of all chapters in this thesis directly result from my own research and studies. Co-authors made invaluable contributions and their associated inputs are declared in the signed co-authorship forms at the beginning of the thesis. Others who assisted with the work are acknowledged in the acknowledgement sections of the individual chapters.

The appendix contains one published conference paper, two co-authored manuscripts and appendices to the core thesis chapters.

- Appendix A contains a lead-authored, published conference manuscript. This conference manuscript investigated the multi-hazard exposure of distributed infrastructure in the West

Coast region. While successfully providing a first multi-hazard exposure assessment for State Highway 6, the paper details the difficulty of including a vulnerability assessment following the decoupling of hazard exposure and hazard magnitude. This investigation directed the PhD project towards the aims outlined above.

- Appendix B contains a published manuscript, co-authored with Professor Tim Davies. This manuscript discusses the need to increase communities' disaster resilience through community adaptation, based on carefully selected impact scenarios derived by community-expert-official collaborations.
- Appendix C is an appendix to Chapter 3; a timeline of key transport events during the first 100 days following the "Kaikōura" earthquake.
- Appendix D is an appendix to Chapter 4; a detailed timeline of participatory governance in Franz Josef between 2016 and 2018.
- Appendix E is an appendix to Chapter 4; a detailed diagram of risk governance actor arrangements in Franz Josef between 2016 and 2018.
- Appendix F is an appendix to Chapter 4; the AF8+ advisory impact scenario maps. This series of maps was developed and used in the participatory workshops.
- Appendix G (G1 – G5) is a second appendix to Chapter 4; workshop notes. The notes detail the conversations and activities within the participatory workshops.

I am the lead-author of Appendix A, C, D, E, F and G. I am the co-author of Appendix B. My contributions to the content of the manuscripts (Appendix A and Appendix B) are outlined in the co-authorship forms.

1.8 References

Aoki, N 2018, 'Sequencing and combining participation in urban planning: The case of tsunami-ravaged Onagawa Town, Japan', *Cities,* vol. 72, pp. 226-236.

Barnes, PM, Bostock, HC, Neil, HL, Strachan, LJ & Gosling, M 2013, 'A 2300-Year Paleoearthquake Record of the Southern Alpine Fault and Fiordland Subduction Zone, New Zealand, Based on Stacked Turbidites', *Bulletin of the Seismological Society of America,* vol. 103, no. 4, pp. 2424-2446.

Barth, NC 2013, *A tectono-geomorphic study of the Alpine Fault, New Zealand* University of Otago, New Zealand.

Bishop, P, Hines, A & Collins, T 2007, 'The current state of scenario development: an overview of techniques', *Foresight,* vol. 9, no. 1, pp. 5-25.

Blake, D, Marlowe, J, Johnston, D (2017) 'Get prepared: Discource for the privileged?', *International Journal of Disaster Risk Reduction,* vol. 25, pp. 283-288.

Börjeson, L, Höjer, M, Drebord, KH, Ekvall, T, Finnveden, G 2006, 'Scenario types and techniques: Towards a user's guide', *Futures,* vol. 38, pp. 723-739.

Bressler, GH, Jennex, ME & Frost, EG 2012, 'X24 Mexico: Stronger Together', *Proceedings of the 9th International ISCRAM Conference*, Vancouver, Canada, p. 5.

Cannon, T 2014, *'Why do we pretend there is 'Community'? Problems of community based-adaptation (CBA) and community based disaster risk reduction (CBDRR)', IDS Povertics, Institute of Development Studies (UK)*, viewed 27/07/18, http://vulnerabilityandpoverty.blogspot.com/2014/04/why-do-we-pretend-there-is-community.html.

Cauffman, S 2015, *Community Resilience Planning Guide for Buildings and Infrastructure Systems, Vol. 1*, NIST Special Publication 1190, U.S. Department of Commerce, United States, vol. 1.

Cavallo, EA & Noy, I 2009, *The Economics of Natural Disasters: A Survey*, IDB Working Paper Series, Inter-American Development Bank, IDB-WP-124.

Centre for Advanced Engineering 1997, *Risks & Realities: A Multi-disciplinary Approach to the Vulnerability of Lifelines to Natural Hazards*, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand.

Chang, SE 2014, 'Infrastructure resilience to disasters', *The Bridge,* vol. 44, no. 3, pp. 36-41.

Chang, SE, McDaniels, TL, Mikawoz, J & Peterson, K 2007, 'Infrastructure failure interdependencies in extreme events: power outage consequences in the 1998 Ice Storm', *Natural Hazards,* vol. 41, no. 2, pp. 337-358.

Cochran, U, Clark, K, Howarth, J, Biasi, G, Langridge, R, Villamor, P, Berryman, K & Vandergoes, M 2017, 'A plate boundary earthquake record from a wetland adjacent to the Alpine fault in New Zealand refines hazard estimates', *Earth and Planetary Science Letters,* vol. 464, pp. 175-188.

Day, TJ 2003, 'Practical Steps in Ensuring Good Risk Communication in a Regional Council', in J Gough (ed.) *Sharing The Future: Risk Communication in Practice,* Centre for Advanced Engineering, Christchurch, pp. 105-116.

De Pascale, G & Langridge, R 2012, 'New on-fault evidence for a great earthquake in AD 1717, central Alpine fault, New Zealand', *Geology,* vol. 40, no. 9, pp. 791-794.

Deligne, NI, Blake, DM, A.J., D, Grace, ES, Hayes, J, Potter, S, Stewart, C, Wilson, G & Wilson, TM 2015, 'Economics of Resilient Infrastructure Auckland Volcanic Field Scenario', *ERI Research Report,* vol. 2015, no. 3, p. 151.

Eiser, JR, Bostrom, A, Burton, I, Johnston, DM, McClure, J, Paton, D, Van Der Pligt, J & White, MPJIJoDRR 2012, 'Risk interpretation and action: A conceptual framework for responses to natural hazards', vol. 1, pp. 5-16.

Fenwick, A 2012, *The Value of Lifeline Seismic Risk Mitigation in Christchurch: Summary Report, June 2012*, New Zealand Lifelines.

Fiji Bureau of Statistics n.d., *Government of Fiji: Regional population mapping*, viewed 5/10/18, https://www.statsfiji.gov.fj/index.php/population-gis-maps.

Fischer, F 2000, *Citizens, experts, and the environment: The politics of local knowledge*, Duke University Press.

Gaillard, J-C & Mercer, J 2013, 'From knowledge to action: Bridging gaps in disaster risk reduction', *Progress in human geography,* vol. 37, no. 1, pp. 93-114.

Gardner, JS 2015, 'Risk complexity and governance in mountain environments', in FP Urbano (ed.), *Risk governance: The Articulation of Hazard, Politics and Ecology*, Springer, Dordrecht, pp. 349-371.

Giovinazzi, S, Wilson, T, Davis, C, Bristow, D, Gallagher, M, Schofield, A, Villemure, M, Eidinger, J & Tang, A 2011, 'Lifelines performance and management following the 22 February 2011 Christchurch earthquake, New Zealand: highlights of resilience', *Bulletin of the New Zealand Society for Earthquake Engineering,* vol. 44, no. 4, pp. 402-417.

Glacier Country Tourism Group 2018a, *Franz Josef Glacier*, viewed 10/08/2018, http://www.glaciercountry.co.nz/explore-our-regions/glaciers-heritage/franz-josef-glacier-area/.

Glacier Country Tourism Group 2018b, *Glaciers & Heritage*, viewed 10/08/2018, http://www.glaciercountry.co.nz/explore-our-regions/glaciers-heritage/.

Gough, J 2000, ‘Perceptions of risk from natural hazards in two remote New Zealand communities’, *The Australasian Journal of Disaster and Trauma Studies,* vol. 2000-2, p. 15.

Gough, J 2001, ‘Changes in understanding, awareness and preparedness for natural hazard risk in Franz Josef Glacier’, *Institute of Geological and Nuclear Sciences science report 2001/22,* p. 19.

Gough, J, Johnston, D, McSaveney, M, 1999 ‘Community response to natural hazard risk at Franz Josef Glacier’, *Institute of Geological & Nuclear Sciences Limited science report 99/10,* p. 35.

Grabowski, Z, Matsler, A, Thiel, C, McPhillips, L, Hum, R, Bradshaw, A, Miller, T & Redman, C 2017, 'Infrastructures as socio-eco-technical systems: Five considerations for interdisciplinary dialogue', *Journal of Infrastructure Systems,* vol. 23, no. 4, pp. 1-9.

Hansman, RJ, Magee, C, De Neufville, R, Robins, R & Roos, D 2006, 'Research agenda for an integrated approach to infrastructure planning, design and management', *International Journal of Critical Infrastructures,* vol. 2, no. 2-3, pp. 146-159.

Hore, K, Gaillard, JC, Davies, T, Kearns, R in review, ‘People’s participation in disaster risk reduction: recentering power’, *Manuscript submitted for publication*.

IEM 2013, *Ensuring Compliance In An All-Hazard Mitigation Plan*, viewed 25/07/18, http://www.iem.com/case-studies/hurricane-pam.

Jones, LM & Benthien, M 2011, 'Preparing for a “Big One”: the great southern California ShakeOut', *Earthquake Spectra,* vol. 27, no. 2, pp. 575-595.

Langridge, R & Beban, J 2011, 'Planning for a safer Franz Josef-Waiau community, Westland District: considering rupture of the Alpine Fault', *GNS Science Consultancy Report,* vol. 217, p. 61.

Langridge, R & Ries, W 2009, 'Mapping and fault rupture avoidance zonation for the Alpine Fault in the West Coast region', *GNS Science Consultancy Report 2009,* vol. 18, p. 47.

Langridge, RM, Buxton, R, Howarth, JD & Ries, WF 2016, *Natural Hazard Assessment for the Township of Franz Josef, Westland District*, GNS Science, Wellington, New Zealand, 2016/33.

McCahon, I, Elms, D & Dewhirst, R 2006, 'West Coast Engineering Lifelines Group Study: Alpine Fault Earthquake Scenario', p. 204.

McCahon, I, Elms, D & Dewhirst, R 2017, 'Improving Resilience to Natural Disasters. West Coast Lifelines Vulnerability and Interdependency Assessment: Main Report', p. 62.

McDaniels, TL, Chang, SE, Hawkins, D, Chew, G & Longstaff, H 2015, 'Towards disaster-resilient cities: an approach for setting priorities in infrastructure mitigation efforts', *Environment Systems and Decisions,* vol. 35, no. 2, pp. 252-263.

McSaveney, M & Davies, T 1998, 'Natural hazard assessment for the township of Franz Josef Glacier and its environs', *Client Report B,* vol. 43714.

MfE 2018, *Getting involved in council plans and plan preparation processes*, viewed 22/06/2019, https://www.mfe.govt.nz/rma/rma-processes-and-how-get-involved/getting-involved-council-plans-and-plan-preparation-processes.

Mitchell, C & Williams, A 2018, *Thin Ice*, viewed 10/08/2018, https://interactives.stuff.co.nz/2018/04/thin-ice/.

Morton, J 2018, *Impact of 1.7m tourists on beautiful NZ*, viewed 10/08/2018, https://www.odt.co.nz/news/national/impact-17m-tourists-beautiful-nz.

National Infrastructure Unit 2015, *The Thirty Year New Zealand Infrastructure Plan 2015*, New Zealand Government, Wellington, New Zealand.

ODI & The World Bank 2015, *Unlocking the 'Triple Dividend' of Resilience: Why investing in disaster risk management pays off*, Overseas Development Institute & The World Bank, London, UK & Washington, US.

Orchiston, C 2013, 'Tourism business preparedness, resilience and disaster planning in a region of high seismic risk: The case of the Southern Alps, New Zealand', *Current Issues in Tourism,* vol. 16, no. 5, pp. 477-494.

Orchiston, C, Mitchell, J, Wilson, T, Langridge, R, Davies, T, Bradley, B, Johnston, D, Davies, A, Becker, J & McKay, A 2018, 'Project AF8: developing a coordinated, multi-agency response plan for a future great Alpine Fault earthquake', *New Zealand Journal of Geology and Geophysics*, pp. 1-14.

Paton, D & Johnston, DM 2017, *Disaster Resilience: An Integrated Approach*, Charles C Thomas, Springfield, Illinois.

Pescaroli, G & Alexander, D 2016, 'Critical infrastructure, panarchies and the vulnerability paths of cascading disasters', *Natural Hazards,* vol. 82, no. 1, pp. 175-192.

Reed, MS 2008, 'Stakeholder participation for environmental management: a literature review', *Biological conservation,* vol. 141, no. 10, pp. 2417-2431.

Remling, E & Veitayaki, J 2016, 'Community-based action in Fiji's Gau Island: a model for the Pacific?', *International Journal of Climate Change Strategies and Management,* vol. 8, no. 3, pp. 375-398.

Robinson, TR, Buxton, R, Wilson, TM, Cousins, WJ & Christophersen, AM 2015, 'Multiple infrastructure failures and restoration estimates from an Alpine Fault earthquake: Capturing modelling information for MERIT', *ERI Research Report,* vol. 2015, no. 4, p. 89.

SARRAH n.d., *Services for Australian Rural and Remote Allied Health: Defining Remote and Rural Context*, viewed 5/10/18, https://sarrah.org.au/content/defining-remote-and-rural-context.

Saunders, W, Grace, E, Beban, J, Johnston, D 2015, 'Evaluating Land Use and Emergency Management Plans for Natural Hazards as a Function of Good Governance: A Case Study from New Zealand', *International Journal of Disaster Risk Science,* vol. 6, pp. 62-74.

Statistics Canada n.d., *Government of Canada: Data and Definitions*, viewed 5/10/18, https://www150.statcan.gc.ca/n1/pub/21-006-x/2008008/section/s2-eng.htm.

Stats NZ 2013, *2013 Census Quickstats about a place: Franz Josef*, viewed 09/08/2018, http://archive.stats.govt.nz/Census/2013-census/profile-and-summary-reports/quickstats-about-a-place.aspx?request_value=14686&parent_id=14681&tabname=&p=y&printall=true.

Stats NZ 2016, *Tourism Satellite Account: 2016*, viewed, http://archive.stats.govt.nz/browse_for_stats/industry_sectors/Tourism/tourism-satellite-account-2016/summary-results.aspx.

Stats NZ n.d., *New Zealand Government: Defining Urban and Rural*, viewed 5/10/18, http://archive.stats.govt.nz/browse_for_stats/Maps_and_geography/Geographic-areas/urban-rural-profile/defining-urban-rural-nz.aspx.

Stirling, M, McVerry, G, Gerstenberger, M, Litchfield, N, Van Dissen, R, Berryman, K, Barnes, P, Wallace, L, Villamor, P & Langridge, R 2012, 'National seismic hazard model for New Zealand: 2010 update', *Bulletin of the Seismological Society of America,* vol. 102, no. 4, pp. 1514-1542.

Tonkin + Taylor & EY 2017, 'Franz Josef Natural Hazards Options Assessment and Cost Benefit Analysis', Auckland, New Zealand.

UNISDR 2015a, 'Global Assessment Report on Disaster Risk Reduction 2015. Making Development Sustainable: The Future of Disaster Risk Management.' United Nations.

UNISDR 2015b, *Sendai Framework for Disaster Risk Reduction 2015-2030*, UNISDR, Sendai, Japan.

UNISDR 2017, *Terminology*, viewed 27/07/17, https://www.unisdr.org/we/inform/terminology.

Wellman, H 1953, 'Data for the study of Recent and late Pleistocene faulting in the South Island of New Zealand', *New Zealand journal of science and technology,* vol. 34, pp. 270-288.

West Coast CDEM Group 2016, *West Coast Civil Defence & Emergency Management Group Plan, Version 2.1*, viewed 10/12/18, https://westcoastemergency.govt.nz/resources/group-plan/.

West Coast Regional Council 2014, 'West Coast Regional Weather Event: Ex Tropical Cyclone Ita, 17 April 2014', p. 30.

Westland District Council 2002, *Westland District Plan*, viewed 21/08/2018, http://district-plan.westland.govt.nz/index.html.

White, I & O'Hare, P 2014, 'From rhetoric to reality: which resilience, why resilience, and whose resilience in spatial planning?', *Environment and Planning C: Government and Policy,* vol. 32, no. 5, pp. 934-950.

Willis, G 2014, *Managing natural hazard risk in New Zealand - towards more resilient communities*, LGNZ, Wellington, New Zealand.

Wilson, J, Espiner, SR, Stewart, E & Purdie, H 2014, *'Last chance tourism' at the Franz Josef and Fox Glaciers, Westland Tai Poutini National Park: A survey of visitor experience*, Centre for Land, Environment & People, Lincoln University, Lincoln, NZ, LEaP Research Report No. 34.

Wodak, J & Neale, T 2015, 'A critical review of the application of environmental scenario exercises', *Futures,* vol. 73, pp. 176-186.

World Bank 2014, *Understanding risk in an evolving world: Emerging Best Practices in Natural Disaster Risk Assessment*, The World Bank, Washington, US.

Yang, K & Pandey, SK 2011, 'Further dissecting the black box of citizen participation: When does citizen involvement lead to good outcomes?', *Public Administration Review,* vol. 71, no. 6, pp. 880-892.

Zorn, C, Davies, AJ, Robinson, TR, Pant, R, Wotherspoon, L & Thacker, S 2018, 'Infrastructure failure propagations and recovery strategies from an Alpine Fault earthquake scenario', *16th European Conference on Earthquake Engineering*, p. 12.

Zorn, C & Shamseldin, AY 2015, 'Post-disaster infrastructure restoration: A comparison of events for future planning', *International Journal of Disaster Risk Reduction,* vol. 13, pp. 158-166.

2. The influence of participatory governance and distributed infrastructure dependence on the disaster resilience of remote communities: a systematic review

Note: Some of the material at the beginning of this chapter is repeated from Chapter 1 because this chapter forms the basis of a standalone paper.

2.1 Abstract

Remote communities are distant from urban centres (often by definition), and so can be required to be largely self-reliant for some time following disasters. This paper systematically reviews and characterises scientific literature (n = 19 studies) concerned with the disaster resilience of remote communities. The aim was to increase understanding of the current extent, range and focus of this field, in order to inform further research and support relevant planning initiatives. The reviewed literature was sparse, recent, and dispersed across disciplines and countries, yet all the studies were concerned with disaster management decision-making, and nearly all (17/19) found that participatory, inclusive governance approaches were key to building resilience. Rates of participation, trust and satisfaction were increased when participation methods: were tailored for specific communities; used a range of participatory methods; and sequenced the involvement of technical and administrative experts in the participatory process. More than a third of publications (7/19) researched community-led participation in remote indigenous communities. The other dominant theme concerned the growing dependency of remote communities on distributed infrastructure networks. The reach of infrastructure networks well beyond the relevant community's immediate vicinity and sphere of influence has greatly increased connectivity and productivity in remote communities, but thereby has also increased infrastructure exposure to disaster damage, and consequent abrupt isolation as remote communities lose essential services. Although all studies were concerned with disaster management decision-making, and most focussed on participatory approaches, only one study documented a process that brought technical experts and government administrators together with communities to make decisions together. No studies concerned participatory governance arrangements that included a focus on increasing the resilience of essential services.

2.2 Introduction

It has been well established that disruption of essential services due to infrastructure damage can exacerbate social and economic disaster impacts. It is also widely recognised that since disasters first and foremost affect the people local to the disaster event, community members need to be involved in disaster resilience decision-making that is likely to affect them (Gaillard & Mercer, 2013). Both findings are particularly relevant for remote communities, where (small) size and (large) distance from urban centres can require self-reliance in the immediate aftermath of a disaster, sometimes for considerable periods of time. Resilience to loss of essential services due to infrastructure damage can also be much lower, due to the growing geographical extent of distributed infrastructure networks that provide essential services. To improve understanding of the existing state of knowledge in this area, this article uses systematic review methodology to identify and assess current research concerned with the disaster resilience of such remote communities.

2.2.1 Remote communities and disaster resilience

Although specific definitions vary, most countries use (small) size and (large) distance from essential services (e.g. hospitals) and urban centres (geographic remoteness) when categorising the "remoteness" of regions and communities (e.g. Fiji Bureau of Statistics, n.d.; SARRAH, n.d.; Statistics Canada, n.d.; Stats NZ, n.d.). The term "community" is often used to denote a group of people living or working in a geographic location, and particularly those who are involved to at least some extent in government or other administrative decision-making affecting the relevant location, as exemplified by all the articles identified in this review. This use of the term "community" has been critiqued on the grounds that it implies a homogeneity that does not exist in practice, meaning that so-called "community based" initiatives that assume this homogeneity risk overlooking existing conflicts and entrenching existing, inequitable power relations (e.g. Cannon, 2014). Acknowledging the validity of this critique, and the essentially heterogenous reality of any population, the term "community" is used in this article to refer to the varied group of people who are (or are likely to be) exposed to the same disaster impacts through social, spatial and/or immediate economic links (Appendix B).

It is now widely recognised that remote communities need to become more actively involved in disaster impact reduction decisions if future disaster impacts are to be reduced. For example, this need is spelled out in the following 2015-2030 Sendai Framework for Disaster Risk Reduction all-of-society guiding principle: 'Disaster risk reduction requires an all-of-society engagement and partnership. It also requires empowerment and inclusive, accessible and non discriminatory participation, paying special attention to people disproportionately affected by disasters, especially the poorest. A gender, age, disability and cultural perspective should be integrated in all policies and practices, and women and youth leadership should be promoted. In this context, special attention should be paid to the improvement of organized voluntary work of citizens' (UNISDR, 2015, 19d, p. 13).

This emphasis on the use of inclusion, participation and empowerment to address social inequities is consistent with the usages of the term "resilience" in academic planning and social science contexts recently identified by White and O'Hare (2014). They found that this "evolutionary" use of the term "resilience" denoted adaption and transformation to address the social factors that increase the inequities of communities and in response to diverse and rapidly changing social, political and natural environments (White & O'Hare, 2014). However, White and O'Hare (2014) have found that, in practice, this transformative potential is largely neutralised by the tendency in engineering, policy and other institutional spheres to use what they label "equilibrist" definitions of "resilience". Where "evolutionary resilience" emphasises social change and adaptation, "equilibrist resilience" is focussed on preserving and restoring the built environment as part of a "return to normal", in which top down, techno-rational approaches are used to deliver universally applicable solutions (White & O'Hare, 2014). This “equilibrist” emphasis is evident in the Sendai Framework global target concerned with infrastructure resilience, which aims to ‘[s]ubstantially reduce disaster damage to critical infrastructure and disruption of basic services’ (UNISDR, 2015, 18d, p. 12), and the associated priority for action, ‘Build Back Better’, which includes promoting ‘the resilience of new and existing critical infrastructure… to ensure that they remain safe, effective and operational during and after disasters in order to provide life-saving and essential services’ (UNISDR, 2015, 33c, p. 21).

The tendency to use the term resilience in one of two opposed senses, identified by White and O'Hare (2014), in effect has meant that conversations about disaster resilience either concern the restoration of the built environment, or focus almost exclusively on the use of inclusive, participatory approaches to increase social resilience. The benefits of inclusive, participatory approaches have been well established, and include more empowerment of community members, more benefits to community members, reduced conflict and increased trust in government decision-making, greater perceptions that decisions are fair, better quality decisions, and better identification of disaster risk (Section 2.2.3) (see Reed, 2008, for a summary). It has also been well established that most communities are becoming increasingly reliant on essential services such as transport, electricity supply, and telecommunications (including calls, texts and data) to function effectively (Gardner, 2015). Damage to the infrastructure networks that provide these essential services, including that caused by natural hazards (e.g. landslides, flooding, earthquakes), can result in the partial and sometimes complete loss of a given community’s essential services for considerable periods of time, at significant social as well as economic cost.

Although the Sendai Framework addresses societal and infrastructure resilience in completely separate sections (UNISDR, 2015), this divide is not apparent in the most recent UNISDR (2017) definition of the term “resilience”: ‘the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions’. This definition of resilience attempts to combine both evolutionary and equilibrist emphases, and so is adopted in this article (noting that we interpret this definition as not requiring the *same* structures and functions, as these may be the cause of decreased disaster resilience; Appendix B).

Therefore, it is well established that both socio-cultural transformation and the provision of essential services are necessary to build the resilience of remote communities. However, to date, the divide identified by White and O'Hare (2014) has resulted in largely parallel bodies of literature focussed either on the relationship between infrastructure and community resilience, or on the use of participatory governance to build resilience at the community level, with very little research combining these findings into more holistic approaches to build community resilience. More integrated approaches to building resilience are required in practice, in which inclusive, participatory approaches are used at the community level to increase the resilience of communities to loss of essential services due to disaster damage to infrastructure, as part of wider initiatives to effect social transformation.

2.2.2 Distributed infrastructure resilience

The rapidly expanding coverage of distributed infrastructure networks (particularly transportation and telecommunication networks) has provided many remote locations with new development opportunities, such as agriculture and tourism ventures (Gardner, 2015). At the same time, the management and provision of the essential services that remote communities rely on to connect regionally, nationally, and internationally, have become increasingly centralised (Gardner, 2015). Increasing centralisation has combined with new development opportunities to increase the dependence of many remote communities on distributed infrastructure networks to provide essential services. This makes distributed infrastructure resilience to the impacts of natural hazards an important component in the resilience of many remote communities, since an event can cause damage to distributed infrastructure that disrupts a dependent community not otherwise impacted by the event.

Engineers have long worked to decrease the physical vulnerability of distributed infrastructure assets. Distributed infrastructure networks, however, are subject to both damage and disruption impacts. Where there is low or no distributed infrastructure redundancy, damage to only one part of a distributed infrastructure network can result in substantial reductions to the service level being provided, or make it impossible for undamaged parts of the network to function. For example, a landslide blocking a road can result in large detours or isolation of the remainder of the road network. Moreover, distributed infrastructure networks are often highly interdependent meaning that impact to one service is likely to have cascading negative consequences for other distributed infrastructure, reducing the service level provided by other networks, and increasing the time required to repair the networks. This has led to increased emphasis on network modelling to demonstrate distributed infrastructure interdependencies and vulnerabilities (Buldyrev et al., 2010).

As a result of these findings, societal as well as technical implications of infrastructure outages are becoming a key focus in many contemporary studies (Chang, 2014), as well as the 2015-2030 Sendai Framework for Disaster Risk Reduction (UNISDR, 2015) (Section 1). Bruneau et al. (2003, p. 736) categorise infrastructure resilience into three interrelated dimensions:

- ‘Reduced failure probabilities
- ‘Reduced consequences from failures, in terms of lives lost, damage, and negative economic and social consequences
- ‘Reduced time to recovery (restoration of a specific system or set of systems to their “normal” level of performance)’.

For example, although maintaining distributed infrastructure networks remains crucial in New Zealand, earlier emphases on “asset-driven” resilience has shifted towards ensuring the provision of essential services, such as prioritising the delivery of power to households and businesses over ensuring the powerline is not damaged (National Infrastructure Unit, 2015). Notably, there has been considerable success from collaboration between infrastructure operators, both in response and pre-disaster mitigation. Again using a New Zealand example, where collaboration between infrastructure operators and emergency managers is now a legislative requirement (MCDEM, 2002), an interdisciplinary collaboration in the late 1990s with government and private infrastructure providers resulted in mitigation before the Canterbury Earthquake Sequence estimated to have saved NZ$60-65 million in direct asset replacement costs alone, and 'the damage would have been greater and the response slower if the steps recommended in… preparatory work… had not been taken' (Fenwick, 2012, p. ii; Giovinazzi et al., 2011). As this would suggest, the recent shift in focus onto the societal implications of service outages has necessarily led to more interdisciplinary research (Chang, 2014; Grabowski et al., 2017; Hansman et al., 2006; McDaniels et al., 2015; Pescaroli & Alexander, 2016), a trend expected to increase into the future as studies build on research and collaborations concerning: multi-hazard implications for service delivery (Centre for Advanced Engineering, 1997; Giovinazzi et al., 2011; IEM, 2013; Zorn & Shamseldin, 2015); the economic implications of service outages (Cavallo & Noy, 2009; Chang et al., 2007; Deligne et al., 2015; Fenwick, 2012; Robinson et al., 2015); and the effects of service outages on community response to disasters (Chapter 4; Chapter 5; Bressler et al., 2012; Cauffman, 2015; Jones & Benthien, 2011; Orchiston et al., 2018). Despite this trend, to date, there is very little research that combines efforts to increase infrastructure resilience with participatory efforts to increase the resilience of communities.

2.2.3 Participatory governance

Direct community involvement in decision-making, focussed on increasing the community's collective resilience to disaster impacts, is an effective way to build resilience at local, community levels (Maskrey, 2011; Pearce, 2003; Reed, 2008). Increasingly these approaches are grouped together under the term "participatory governance", which has been defined as the direct involvement of community stakeholders in administrative decision-making and management processes (Aoki, 2018; Reed, 2008; Yang & Pandey, 2011), where a "stakeholder" is a person or organisation affected by the decision-making process and outcome.

Participation has been defined by Reed (2008, p. 2418) as: 'a process where individuals, groups and organisations choose to take an active role in making decisions that affect them.' Participation literature dates back decades; Cornwall (2011) notes at least 50 years of research into participation, while Rowe and Frewer (2005) note sporadic research interest in participation for centuries or longer. Reed (2008) summarises six broad phases of stakeholder participation over the last 60 years:

1) pragmatic, anti-modernisation awareness-raising that the application of scientific rationality cannot solve all societal problems (late 1960s) (see Van Tatenhove & Leroy, 2003, for a review);
2) incorporating community members' perspectives in data collection and gathering (1970s);

3) development of techniques that recognised community members' local knowledge (1980s);
4) participation as a norm in the sustainable development agenda (1990s);
5) critique of participation and disillusionment over its limitations and failings (early 2000s); and
6) consensus over best-practice (late 2000s into 2010s).

These developments have emerged in parallel in a range of disciplinary contexts and topic areas, including social activism, adult education, applied anthropology, complex systems science, natural resource management, and ecology (Reed, 2008).

Reed (2008) has established that arguments for the inclusion of participatory processes in decision-making can generally be classified into normative or pragmatic categories (see Reed, 2008, for a detailed summary). Normative reasoning is based on the understanding that people have a right to participate in decision-making which affects them. Pragmatic reasoning focusses on the capacity of participatory processes to deliver higher-quality outputs. Again, the benefits of participation have been well established, and include:

- increased likelihood that government decisions are perceived as fair (Richards et al., 2004);
- increased trust in government (decisions) (Bohensky et al., 2011a; Bohensky et al., 2011b; Peterson et al., 2003; Ravera et al., 2011; Richards et al., 2004; Tress & Tress, 2003);
- collaborative relationships, even following previous conflict (Kahane, 2012; Oteros-Rozas et al., 2013; Plieninger et al., 2013; Ravera et al., 2011; Stringer et al., 2006);
- increased social learning (Blackstock et al., 2007; Volkery & Ribeiro, 2009);
- participant education (Aoki, 2018; Hicks et al., 2014; Murphy et al., 2014; Orchiston et al., 2013);
- knowledge integration and co-generation (Bohnet, 2010; Kok et al., 2007; Tress & Tress, 2003; von Wirth et al., 2014; Walz et al., 2007);
- increased capacity to utilise (integrated and co-generated) knowledges, leading to empowerment (Greenwood et al., 1993; Kok et al., 2007; Macnaghten & Jacobs, 1997; Reed et al., 2013; Wallerstein, 1999; Walz et al., 2007);
- participants gaining a sense of ownership over the process and outcomes (Richards et al., 2004);
- more robust research (Reed et al., 2008; Reed et al., 2006);
- identification of new risks (including "root causes"), vulnerabilities, and "solutions" (Butler et al., 2016; de Andrade & Szlafsztein, 2015; Ellemor, 2005; Kok et al., 2007; Manuel-Navarrete et al., 2011; Murphy et al., 2014);
- increased likelihood community members benefit from "solutions" (Butler et al., 2016; Dougill et al., 2006; Millennium Assessment Board, 2005; Palomo et al., 2011; Walz et al., 2007);
- higher-quality decisions (Beierle, 2002; Fischer, 2000; Fritsch & Newig, 2012; Hill et al., 2010; Koontz, 2005; Newig, 2007; Palomo et al., 2011; Ravera et al., 2011; Tress & Tress, 2003);
- reduced implementation costs (Reed, 2008).

However, disadvantages of participatory processes have also been documented. When unsuccessful, participation processes can lead to unexpected negative interactions with existing power structures (Kothari, 2001), reinforce existing privileges (Cooke & Kothari, 2001; Nelson & Wright, 1995), and cause participation fatigue (Burton et al., 2004; Cooke, 2004; Cosgrove & Rijsberman, 2000; Duane, 1999; Reed, 2008; Reed et al., 2013; Wondolleck & Yaffee, 2000). These pitfalls are especially likely to manifest where some stakeholders do not have the capacity or power to respond (Arnstein, 1969; Reed et al., 2013). For example, Broad et al. (2007) observed a process where participants chose between a narrow range of scenarios already developed by a risk-averse government agency, and the agency retained the right to overturn any decision made by the participants (Reed et al., 2013). Further, while expert input is often an important part of the participatory process, expert authority carries the risk of biasing outcomes unless it is carefully balanced (Reed et al., 2013). Participatory processes also require considerable time investment, which can limit the use of participation, and also means that there may not be time to address all of the project aims (Reed et al., 2013).

Community participation that does not involve government decision-making and government decisions made without participation of non-state actors have both been found to be ineffective at successfully effecting change (Ackerman, 2004). The clear benefits that participation brings to decision-making have contributed to a convergence between the participatory and governance fields beginning in the 1990s in response to 'evident democratic deficits' in high income countries (Cornwall, 2011, p. xvii). This convergence intensified in the wake of the landmark World Bank (1998) *World Development Report 1998/1999* (Cornwall, 2011).

While the importance of participation has moved up the political agenda, featuring for example in the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015), in practice the development of effective participatory governance has lagged far behind (Ackerman, 2004; Díez et al., 2015; Howard, 2018). Rowe and Frewer (2005) have suggested that a contributing factor here may be the abundance of participation methodologies available. Identifying and synthesising over 100 methodologies to produce a typology of participation, they note that 'there are undoubtedly more' (Rowe & Frewer, 2005, p. 256). Where Rowe and Frewer (2005, p. 252) suggest that this abundance has contributed to uncertainty concerning best practice, Fung (2006, p. 66) argues that the contexts in which participation methodologies are applied are so specific that there can be no 'canonical form', and that participation methodologies should be 'legion'. Both agree on the need for clarification concerning key methodological elements, including types of communication, recruitment and participants, to ensure advances in methodologies are better documented and used (Fung, 2006; Rowe & Frewer, 2005).

Participation methodology typologies have been used since Arnstein (1969, p. 217) introduced her early and influential example, categorising types of participation methodology as a 'ladder of citizen participation' ranging from 'nonparticipation' through 'degrees of tokenism' to 'degrees of citizen power'. Subsequent typologies have become increasingly focussed on governance, with the Aoki

(2018, p. 231) adaptation of the Fung (2006) typology the most recent and comprehensive example (Figure 3). This typology has been used to inform and guide critical analysis in this review. Making it possible to break each methodology out into a series of subordinate typologies (including participant type and role, modes of recruitment and communication), this typology enables analysis of the wide range of different participatory methods required by the correspondingly diverse range of contexts within which they are applied (Aoki, 2018; Fung, 2006).

Fung (2006)

Participant selection methods

More exclusive ↑
Expert administrators
Elected representatives
Professional stakeholders
Lay stakeholders
Random selection
Open, targetted recruiting
Open, self-selection
More inclusive ↓ Diffuse public sphere

Modes of communication and decision

Least intense ↑ Listen as spectator
Express preferences
Develop preferences
Aggregate and bargain
Deliberate and negotiate
Most intense ↓ Deploy technique and expertise

Extent of authority and power

Least authority ↑ Personal benefits
Communicative influence
Advise and consult
Co-governance
Most authority ↓ Direct authority

Aoki (2018)

Types of participants

More exclusive ↑ Expert administrators
Elected representatives
Professional stakeholders, hired by government
Organised interest groups (e.g. business associations)
Lay stakeholders
Concerned general public
More inclusive ↓ Diffuse public sphere

Modes of recruitment

Most coercive ↑ Legal mandate
Employment (professional assignment)
Social obligation
Targetted invitation
Open invitation
Least voluntary ↓ Self-initiative by the participants themselves

Modes of communication

Least intense ↑ Listen as spectator
Express preferences
Develop preferences
Aggregate preferences and propose
Deliberate and negotiate
Most intense ↓ Deploy technique and expertise

Roles of participants

Lowest influence ↑ Passive audience
Active audience
Advocates
Advisors and consultants
Joint decision makers (co-governance)
Highest influence ↓ Sole decision makers

Figure 3. Typologies for understanding participation within the participatory governance sphere by Fung (2006) and Aoki (2018), including highlighted differences between the two typologies.

Finding that the 'scope of participation' aspect of the Fung (2006) typology conflates 'types of participants' and 'modes of recruitment', Aoki (2018, p. 230) distinguishes these, introducing modes of recruitment as a fourth key component of participatory governance. The 'types of participants' domain refers to 'civicness, defined as the extent to which participants are close to the public sphere, as opposed to being close to authorities' (Aoki, 2018, p. 230). The 'modes of recruitment' domain refers to how voluntary or coerced the participation is (these are defined in detail by Aoki, 2018, p. 230). 'Modes of communication' provides a spectrum of communication defined in relation to the need for input from participants, while 'roles of participants' refers to the amount of influence the participants have on the participatory process and outcomes (Aoki, 2018, p. 230).

Note that the application of this typology in a remote Japanese community meant that the Aoki (2018) paper was identified through this systematic review methodology as a part of the literature on the resilience of remote communities to natural hazards.

2.2.4 Systematic review

Systematic review methodology was used to identify and provide a critical appraisal of current research concerned with the resilience of remote communities at risk of isolation following disasters. Ford et al. (2011, p. 328) define a systematic review as 'a summary and assessment of the state of knowledge on a given topic or research question, structured to rigorously summarize existing understanding'. Systematic reviews use a strict, reproducible methodology. Because they are useful for synthesising emerging, dispersed, and highly interdisciplinary research fields (Haddaway & Pullin, 2014), systematic reviews have been integral to the medical field for many years. More recently, the advantages of this methodology have been recognised and utilised in other research fields, although few systematic reviews have addressed the hazards field (Jurgilevich et al., 2017; Spector et al., 2018). In a relevant and recent exception, Spector et al. (2018) reviewed literature concerned with rural resilience in New Zealand.

The application of this strict methodology distinguishes systematic reviews from other meta-analytic reviews, which also bring together and synthesise evidence from bodies of relevant literature to provide meta-analyses of broader research fields (Ford et al., 2011; Haddaway & Pullin, 2014). Keyword searching of electronic databases is used in all these methodologies, and also constitutes a recognised limitation. Even in medical fields, where the use of key terms is highly consistent, it is not possible to use keyword searches that will capture all relevant articles in a systematic review (Jurgilevich et al., 2017). This limitation can be greater in social science and interdisciplinary contexts, where there is far less agreement on the definitions of key terms, and a much wider range of terms can be used to describe similar phenomena. To mitigate this potential limitation, this study used several terms that denote similar concepts. The number of synthesis studies captured also helped to mitigate this limitation. These include an early synthesis of the field by Ellemor (2005) and the more developed evidence bases concerning factors affecting the resilience of remote communities to natural hazards provided by Beeton and Lynch (2012) and Gardner (2015), as well as a recent synthesis of participation methodologies by Aoki (2018). These synthesis studies help to reduce the potential shortcoming of keyword searching, and were particularly useful for, and influential within, the thematic analysis.

2.3 Method

To identify relevant peer-reviewed publications in the first step of this review, key terms were used to search online publication databases Scopus (www.scopus.com; provided by Elsevier) and Web of Science (www.webofknowledge.com; provided by Thomson Scientific), in March 2018. Scopus, Web of Science and Google Scholar (scholar.google.com; provided by Google) are the three most popular multidisciplinary databases (Waltman, 2016). Google Scholar was not used because it does not have a defined coverage policy, includes non-peer-reviewed literature, and does not offer comprehensive advanced search capabilities, results refinement, or allow for large downloads of citation data, which are crucial for systematic reviews of any type (Halevi et al., 2017). Scopus and Web of Science have complementary biases, so using these databases in combination can provide more comprehensive results than searching either in isolation (Meho & Yang, 2007; Waltman, 2016). It is worth noting, however, that Google Scholar has been found to have better coverage of multidisciplinary subject areas and social sciences than Scopus or Web of Science (Halevi et al., 2017).

The review was focussed on literature concerned with disaster resilience in remote communities. Because several terms are used to denote similar concepts, the first searches were conducted using various combinations of the following terms: 'Communit*,' 'Remote', 'Isolat*', 'Disaster', 'Resilien*' and 'Emergency' (Table 1). These searches yielded 78% of the total publications captured in Scopus and Web of Science searches (Table 1). To reduce the risk of excluding studies focussed on specific hazards, searches were conducted with seven additional specific hazard terms (e.g. 'Earthquake' and 'Flood*') replacing 'Disaster' and 'Emergency' in the search strings. These searches yielded 6% of the total (Table 1). After an early review of abstracts indicated a heavy emphasis on disaster management decision-making, a final search was conducted with search strings including the term 'Governance', which yielded a further 9% of total publications. In all, a variety of combinations of 13 terms were used in to create 15 search strings (Table 1). The use of multiple search strings was designed to decrease the potentially limiting effect of each specific search string. Terms and search strings were reviewed by a second researcher.

A combined total of 1,718 publications resulted from Web of Science and Scopus searches. Of these, 681 were duplicates, leaving 1,037 studies (Figure 4). Studies were then excluded from the review if they were not: i) concerned with the resilience of human communities to disasters caused by natural hazards; and/or ii) focussed on remote communities at risk of isolation due to disaster impacts (Figure 4). Examples of articles excluded include: medical, psychological and ecological studies of individual and ecosystem resilience; studies discussing national or international-level policies only, with little to no discussion of the way that these policies might apply at specific local levels; and structural engineering studies. To increase accuracy, a second researcher peer-reviewed both the list of studies included in the final review and the list of studies that had been removed following abstract screening. Overall, only 19 studies were found to be concerned with resilience to natural hazards and focussed on remote communities at risk of isolation due to disaster impacts (Figure 4).

Table 1. The number of articles returned from each database, by search string.

Search terms	Number of studies returned	
	Scopus	Web of Science
Communit* AND Remote AND Disaster*	447	216
Communit* AND Isolat* AND Disaster*	304	142
Resilien* AND Isolat* AND Disaster*	98	74
Resilien* AND Isolat* AND Emergency	43	23
Governance AND Remote AND Disaster*	39	20
Governance AND Remote AND Resilien*	36	34
Governance AND Isolat* AND Resilien*	34	41
Governance AND Isolat* AND Disaster*	28	20
Resilien* AND Communit* AND Isolat* AND Flood*	27	23
Resilien* AND Communit* AND Isolat* AND Earthquake*	17	17
Governance AND Isolat* AND Emergency	12	7
Resilien* AND Communit* AND Isolat* AND Volcan*	6	5
Resilien* AND Communit* AND Isolat* AND Avalanch*	1	2
Resilien* AND Communit* AND Isolat* AND Landslid*	1	1
Resilien* AND Communit* AND Isolat* AND Rockfall*	0	0
Total:	1,093	625

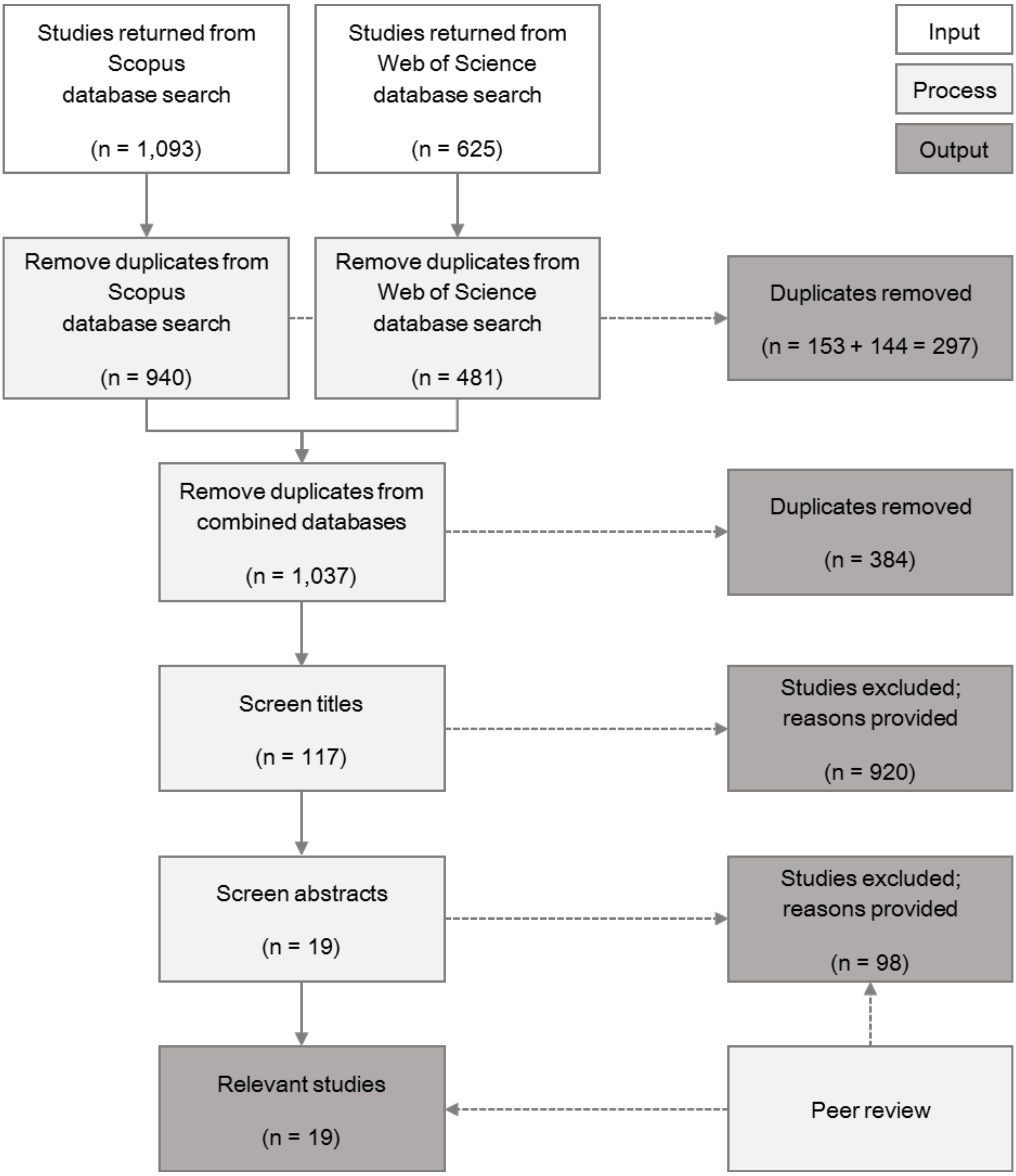

Figure 4. Visualisation of the systematic review process.

2.3.1 Data analysis

A general inductive approach was used to analyse the 19 relevant studies, following Thomas (2006). Each study was read in full, and relevant quotes were compiled in a table. The quotes were coded to relevant summary words or phrases and grouped into themes and categories in an iterative process. The themes and categories allowed easy sorting of the quotes for analysis, which in turn highlighted trends in the studies.

Since most studies were focussed on participatory governance, the Aoki (2018) participation typology was used to guide the critical analysis (Section 2.2.3). However, it is important to note that while all identified studies were analysed according to this typology, not all studies were concerned with participatory governance as defined by Aoki (2018). For this review, we define "participatory governance" as involving the direct involvement of *community stakeholders* in administrative decision-making and management processes, where a "stakeholder" is a person or organisation affected by the decision-making process and outcome (Section 2.2.3). Aoki (2018, p. 226, emphasis added) defined participatory governance as requiring the 'direct involvement of *citizens*'.

Study meta-data, including year of publication, number of citations, publication title, lead-author institution, and location of lead-author were also considered. In-text data were also identified according to primary author and study locations, sectors involved in research or publication, and primary hazard(s) studied. Additionally, *VOSviewer* (www.vosviewer.com) software was used to visualise the reviewed field. *VOSviewer* uses multidimensional scaling to construct and visualise bibliometric networks, so that the distance between items indicates the strength of relations between them (Van Eck & Waltman, 2007). Developed by Van Eck and Waltman (2007), and termed the Visualisation Of Similarities (VOS) method, *VOSviewer* normalises data from a co-occurrence matrix using a similarity measure known as association strength (for details of this measure see van Eck and Waltman, 2010). *VOSviewer*'s bibliographic Coupling Analysis was used to identify and visualise references shared between publications, while Citation Analysis was used to identify and visualise the number of times reviewed articles cited one another.

2.4 Research field characteristics

The systematic review yielded 19 studies concerned with the disaster resilience of remote communities. The studies, including citation counts, are listed in Table 2. All were published in or after 2006, and the majority after 2014 (Figure 5), reflecting the emerging nature of the field (Section 2.4.1). This is supported by citation analysis, which shows that although 15 of the articles share at least one reference, only one (of 19) cites another article also included within this review. Although often building upon the same body of literature, these studies remain discrete. The 19 reviewed studies were published within 17 different journals and one book (Table 2), and lead-authored from 18 different institutions (Table 3). This low connectivity is consistent with a converging interest in this topic area from a range of disciplines and research fields (Section 2.4.1).

Although the reviewed sample was too small to yield statistically significant findings, it is notable that only Australia, Canada, and New Zealand feature more than once as study area locations, with each featuring three or four times (Figure 6). Further, all three studies focussed on Canadian communities (Amaratunga, 2014; Cox & Hamlen, 2015; Murphy et al., 2014) and two of the three studies focussed on Australian communities (Beeton & Lynch, 2012; Ellemor, 2005) involve or discuss indigenous communities, as do a study in Fiji (Remling & Veitayaki, 2016) and a study in the Soloman Islands (Otoara Ha'apio et al., 2018).

All of the studies identified through the systematic methodology were not only concerned with the resilience of remote communities to natural hazards, but were also concerned with disaster management decision-making, and all but Orchiston et al. (2013) and Chapter 3 were concerned with participatory governance. This was unexpected, because the majority of studies (17/19) were identified using key terms that did not refer to participation or governance, and this topic was not part of the inclusion criteria. The consistency of this focus across diverse geographic study locations, sectors, hazards, disciplines, institutions, and countries, indicates a strong convergence towards participatory governance.

Table 2. The 19 relevant studies, including Scopus citation counts (retrieved in July 2018), and a summary of the studies/rationale for their inclusion.

Study	Study title	Publication title	Citations	Study summary
Amaratunga (2014)	Building community disaster resilience through a virtual community of practice (VCOP)	International Journal of Disaster Resilience in the Built Environment	3	Pre-disaster facilitation to increase the resilience of remote communities in Canada by encouraging cross-community communication.
Aoki (2018)	Sequencing and combining participation in urban planning: The case of tsunami-ravaged Onagawa Town, Japan	Cities	1	Post-disaster observation of community and stakeholder collaboration during recovery from a Tsunami in a remote Japanese community.
Beeton and Lynch (2012)	Most of nature: A framework to resolve the twin dilemmas of the decline of nature and rural communities	Environmental Science & Policy	17	Pre-disaster advocation of framework to improve conservation and remote community policies to ensure sustainability of both communities and nature in Australia.
Blakely and Fisher (2017)	Assessing non-metro recovery across two continents: issues and limitations	Disasters	0	Post-disaster observation case studies of natural hazards affecting remote communities in Australia and the United States, and the response and recovery strategies used.
Cox and Hamlen (2015)	Community Disaster Resilience and the Rural Resilience Index	American Behavioral Scientist	12	Pre-disaster facilitation to increase the resilience of remote communities in Canada by encouraging cross-community communication.
Davies et al. (2017) [Chapter 3]	Transport infrastructure performance and management in the South Island of New Zealand, during the first 100 days following the 2016 Mw 7.8 "Kaikōura" earthquake	Bulletin of the New Zealand Society for Earthquake Engineering	7	Post-disaster observation case study of infrastructure recovery from an earthquake event in New Zealand, including implications for remote communities.

de Andrade and Szlafsztein (2015)	Community participation in flood mapping in the Amazon through interdisciplinary methods	Natural Hazards	4	Pre-disaster facilitation to include community members in risk reduction planning through participation in flood mapping in Brazil.
Ellemor (2005)	Reconsidering emergency management and indigenous communities in Australia	Global Environmental Change Part B: Environmental Hazards	26	Pre-disaster advocation that working with indigenous communities to reduce disaster risk will improve emergency management in Australia.
Espiner and Becken (2014)	Tourist towns on the edge: Conceptualising vulnerability and resilience in a protected area tourism system	Journal of Sustainable Tourism	25	Pre-disaster observation of the vulnerability and resilience of remote communities in New Zealand.
Gardner (2015)	Risk complexity and governance in mountain environments	Risk Governance: The Articulation of Hazard, Politics and Ecology	2	Overview of risk complexity and governance of remote communities in mountain environments, through pre-disaster observation.
Gupta and Sharma (2006)	Compounded loss: The post tsunami recovery experience of Indian island communities	Disaster Prevention and Management	18	Observation of the post-disaster tsunami recovery of Indian island communities.
Hicks et al. (2014)	An interdisciplinary approach to volcanic risk reduction under conditions of uncertainty: A case study of Tristan da Cunha	Natural Hazards and Earth System Sciences	6	Pre-disaster facilitation to increase the resilience of Tristan da Cunha island community to volcanic hazards.
Manuel-Navarrete et al. (2011)	Critical adaptation to hurricanes in the Mexican Caribbean: Development visions, governance structures, and coping strategies	Global Environmental Change	49	Post-disaster observation of development visions, governance structures and coping strategies for remote communities vulnerable to hurricanes in the Mexican Caribbean.

Marin et al. (2015)	Social capital in post-disaster recovery trajectories: Insights from a longitudinal study of tsunami-impacted small-scale fisher organizations in Chile	Global Environmental Change	6	Post-disaster observation of the importance of social capital for the recovery of remote communities following a tsunami in Chile.
Murphy et al. (2014)	Planning for disaster resilience in rural, remote, and coastal communities: Moving from thought to action	Journal of Emergency Management	3	Pre-disaster facilitation to increase the resilience of remote communities in Canada by encouraging cross-community communication.
Orchiston (2013)	Tourism business preparedness, resilience and disaster planning in a region of high seismic risk: The case of the Southern Alps, New Zealand	Current Issues in Tourism	16	Pre-disaster observation of tourism business disaster planning for remote communities in New Zealand.
Orchiston et al. (2013)	The 2009 New Zealand West Coast shakeout: Improving earthquake preparedness in a region of high seismic risk	Australasian Journal of Disaster and Trauma Studies	1	Pre-disaster facilitation of an earthquake disaster scenario exercise for remote communities in New Zealand.
Otoara Ha'apio et al. (2018)	Transformation of rural communities: lessons from a local self-initiative for building resilience in the Solomon Islands	Local Environment: The International Journal of Justice and Sustainability	0	Post-disaster observation of a community-led initiative for the relocation of a rural community in the Solomon Islands
Remling and Veitayaki (2016)	Community-based action in Fiji's Gau Island: A model for the Pacific?	International Journal of Climate Change Strategies and Management	4	Observation of pre-disaster community-based action, aiming to increase resilience to climate change for a remote island in Fiji.

2.4.1 An emerging interdisciplinary field

Analysis of meta-data indicates that research into potentially-isolated communities is a recent phenomenon. With the exceptions of Ellemor (2005) and Gupta and Sharma (2006), all publications (17/19) are from 2011 onward (Figure 5).

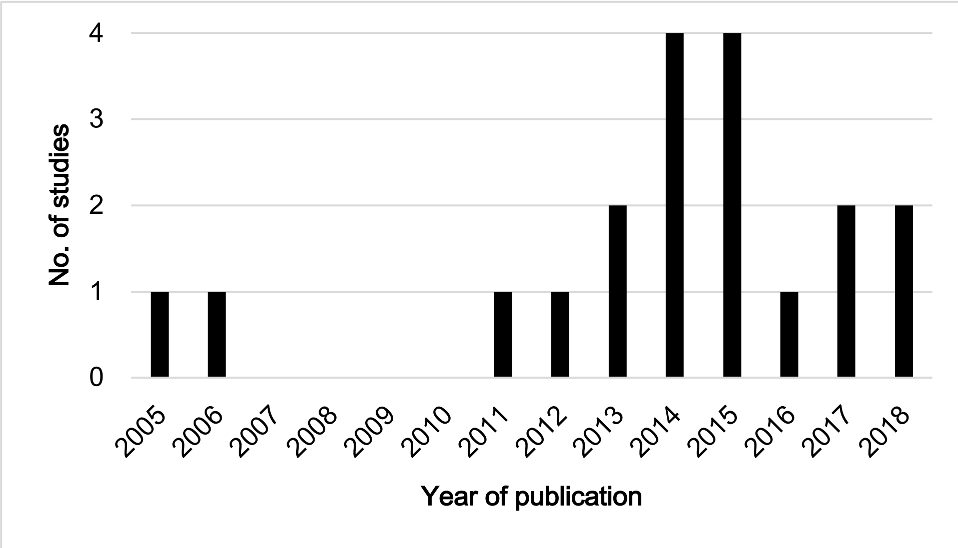

Figure 5. A graph showing the number of relevant studies published by year. The 2018 bar only includes studies published by March 2018.

The emergent nature of the field is also demonstrated by citation analysis, which reveals that most (15/19) of the relevant studies have at least one citation in common. These links between studies indicate that the studies are drawing from and building on the same body of literature. However, only one study (Cox & Hamlen, 2015) cites another study also included within this review (Murphy et al., 2014), suggesting that this research field is emerging as a result of convergence from a range of disciplinary contexts, rather than developing from within a single discipline.

Publication and authorship data are similarly indicative of disciplinary convergence as part of a wider trend. The studies are published in 17 journals and one book (Table 2), with *Global Environmental Change* the only publication to feature more than once (twice) in the list of studies. *Global Environmental Change Part B: Environmental Hazards* also features once, effectively meaning *Global Environmental Change* features three times. Authorship affiliation is similarly diverse, with lead authors affiliating to 18 institutions (Table 3). The University of Otago (New Zealand), is the only institution to feature twice (the lead-author of both University of Otago studies is also the only lead-author to feature twice in the list of studies). All other (17) studies constitute the sole piece of research within this review by the relevant lead-author, as well as the sole piece of research affiliated to the relevant institution.

Whereas the lead authors of these articles are affiliated to 18 different institutions, there is more crossover in the nationality of these institutions. Institutions based in Canada and New Zealand have produced the most studies, at four each. Three were produced in Australia, two in Sweden, two in the United Kingdom, and one each in Brazil, Fiji, India, and Singapore (Table 3, Figure 6).

Table 3. Lead-author institution, by country.

Lead-author institution	**No. of studies**	**Country**	**No. of studies**
Emergency Management Australia	1	Australia	3
University of Queensland	1		
University of Sydney	1		
Universidade Federal do Pará	1	Brazil	1
Royals Road University	1	Canada	4
University of Manitoba	1		
University of Victoria	1		
Wilfrid Laurier University	1		
The University of the South Pacific	1	Fiji	1
Socio Economic and Educational Development Society (SEEDS) India	1	India	1
Lincoln University	1	New Zealand	4
University of Canterbury	1		
University of Otago	2		
National University of Singapore	1	Singapore	1
Södertörn University	1	Sweden	2
Stockholm University	1		
King's College London	1	United Kingdom	2
University of East Anglia	1		

2.4.2 Study focus

13 countries were studied within the 19 publications. Although this make the study locations more geographically diverse than the nine countries of the lead-author institutions, 10 of the 20 study locations concern either New Zealand (4), Australian (3), or Canadian (3) (Figure 6). The other 10 study locations appear only once. Note: Blakely and Fisher (2017) studied both Australia and the United States.

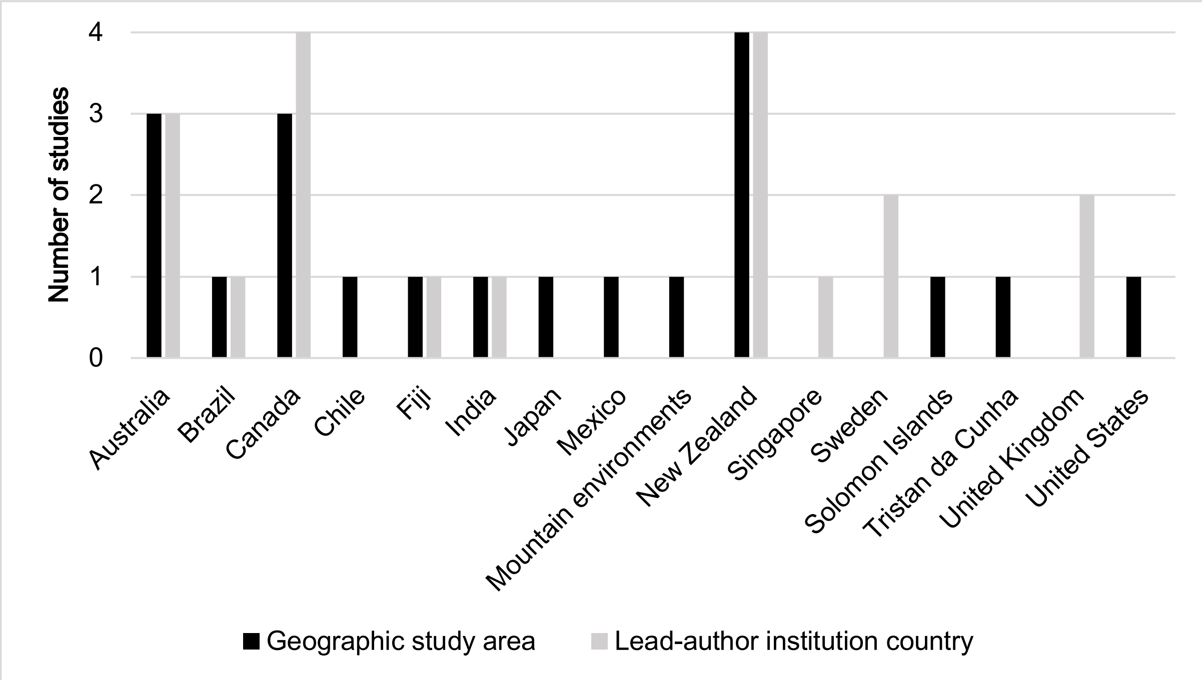

Figure 6. Graph showing locations of studies and locations of lead-authors.

As settler colonies, Australia, Canada and New Zealand share a recent history of colonisation of indigenous communities. Seven (of the 19) studies directly involve or discuss indigenous communities, including all three studies focussed on Canadian communities (Amaratunga, 2014; Cox & Hamlen, 2015; Murphy et al., 2014), two of the three Australian studies (Beeton & Lynch, 2012; Ellemor, 2005), and the studies concerned with Fiji (Remling & Veitayaki, 2016) and the Solomon Islands (Otoara Ha'apio et al., 2018). Note that the three Canadian studies all result from the same targeted government research funding initiative (Amaratunga 2014). While this sample size (of 19) is too small to draw strong conclusions, the predominance of studies from the three contributing post-colonial countries is suggestive. It is possible that recent histories of colonisation have contributed to an emerging focus on the cultural and economic importance of remote communities, and their exposure to isolation following disasters (Section 2.4.2). As the subordination of one nation by another, colonisation by definition has resulted in loss of autonomy for indigenous communities, who continue to experience political oppression and excessive bureaucratic control (Kirmayer et al., 2011). In Australia and Canada, moreover, this historical process has often included the forcible removal and or restriction of indigenous people to remote locations (Cox & Hamlen, 2015; Ellemor, 2005; Murphy et al., 2014), where resilience has been further eroded by the devaluation of traditional local knowledges, practices and responsibilities tied to specific locations or regions (Ellemor, 2005). Engaging with such communities with sensitivity has the potential to revalue well-developed indigenous environmental discourse that is of great value for work focussed on building socio-cultural and environmental resilience (Beeton & Lynch, 2012). Notably, no studies were identified that focussed on the disaster resilience of remote indigenous communities in New Zealand. This is surprising, given that New Zealand is the most highly represented study location, and the country has a policy of bi-culturalism with an even more recent history of colonisation than Australia and Canada.

This finding is, however, consistent with Spector et al. (2018), whose systematic approach similarly failed to identify literature concerned with the resilience of indigenous rural communities in New Zealand, indicating that further study in this area is needed.

Other possible factors in the predominance of study locations in Australia, Canada and New Zealand include the often sparsely populated geography of these countries, and the prevalence of strong disaster management programmes. The economic and commercial development that follows colonisation is another likely factor. Australia, Canada and New Zealand are all high-income countries, due to core businesses such as commercial agriculture, mining, and more recently tourism, which are reliant upon distributed infrastructure (Gardner, 2015). Growth of these businesses, and associated populations, in remote locations has led to increased dependence upon distributed infrastructure. Further, Australia, Canada and New Zealand all have strong disaster management programmes and funding programmes capable of identifying the need for, and enabling research into, the disaster resilience of remote communities.

The sectors that were either involved with the research or were the main research focus are shown in Figure 7. Many studies (13/19) focussed on more than one sector. The community sector featured in 15 of the 19 studies (of this 15, seven studies focussed on indigenous communities), the government sector was the focus of 13 studies, and seven studies focussed on the private sector (Figure 7).

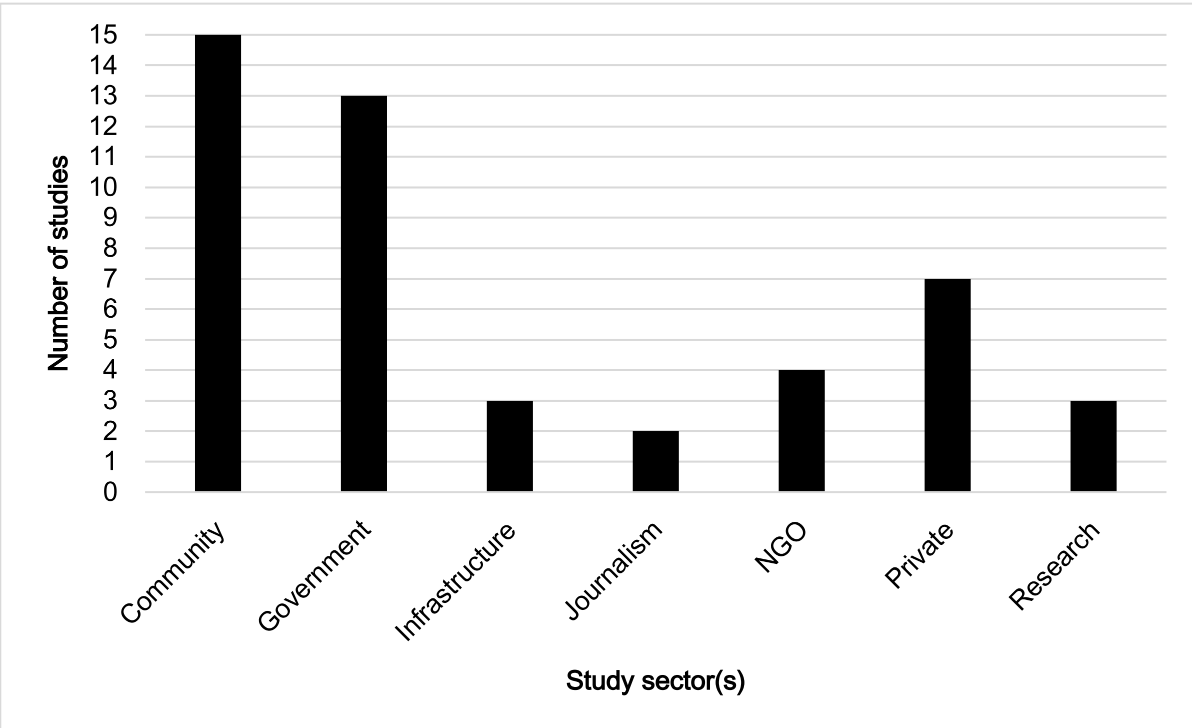

Figure 7. Sectors involved with the research or studied.

Most of the studies (11/19) were focussed on a specific hazard (Figure 8). Three studies were concerned with hazards associated with climate change, three with hazards posed by earthquakes and three with tsunami-related hazards. Flooding and volcanic hazards were the focus of one study each.

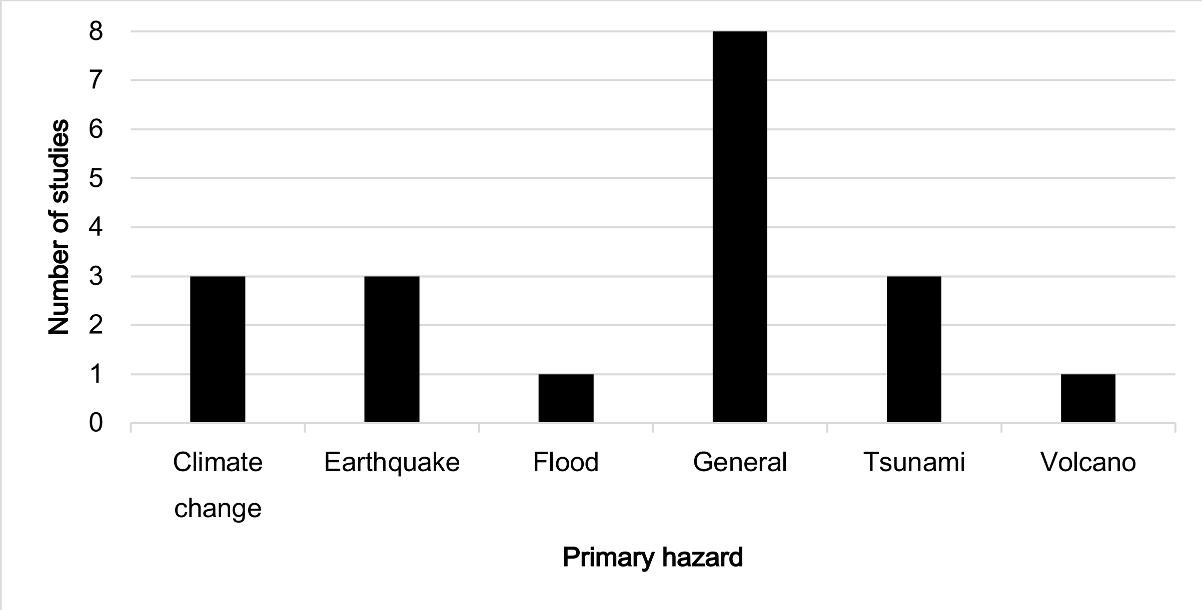

Figure 8. A graph showing the primary hazard focus within the studies.

2.4.3 Study methodologies and participatory governance techniques

All reviewed literature was concerned with disaster management decision-making, and most publications were focussed on participatory governance. This consistency across such an otherwise diverse group of studies is strongly indicative of a convergence across disciplines and institutes towards participatory governance.

The following categorisation of methodologies and techniques draws from the distinction Bishop et al. (2007) make between methodology, as the order of steps in an overarching research process, and technique, which concerns the way that each step is carried out. According to this distinction, the methodologies used in the reviewed literature can be broadly categorised into three types (again, note that some constitute more than one of these types):

i. four articles synthesised a relevant evidence base (4/19) (Aoki, 2018; Beeton & Lynch, 2012; Ellemor, 2005; Gardner, 2015) (note that there was no cross over between the articles reviewed in this study and those synthesised in these four studies);

ii. six articles reported on case studies in which researchers helped facilitate a new participatory methodology (6/19) (Amaratunga, 2014; Cox & Hamlen, 2015; de Andrade & Szlafsztein, 2015; Hicks et al., 2014; Murphy et al., 2014; Orchiston et al., 2013), and

iii. ten articles reported on researcher observation of a case-study (10/19) (Aoki, 2018; Blakely & Fisher, 2017; Chapter 3; Espiner & Becken, 2014; Gupta & Sharma, 2006; Manuel-Navarrete et al., 2011; Marin et al., 2015; Orchiston, 2013; Otoara Ha'apio et al., 2018; Remling & Veitayaki, 2016).

Studies were also broadly categorised according to the Aoki (2018) participation typology (Section 2.2.3) according to disaster management decision-making and participatory techniques, both for ease of reference and as a starting point for the analysis. Only four (of 19) studies are concerned with participatory approaches that bring expert administrators together with public or community representatives, and of these, only Aoki (2018) reports on a case study in which decision-making responsibility is shared between expert administrators and public representatives. Additionally, of the seven studies concerned with building the disaster resilience of remote indigenous communities, only the Blakely and Fisher (2017) comparison of issues affecting remote communities in Australia and the United States discusses co-governance arrangements in which expert administrators share decision-making authority with representatives of remote communities. This suggests that the need identified by Ellemor (2005) for more partnership between government agencies and indigenous communities is still urgent, particularly in view of Ackerman (2004), who finds that the most successful participatory efforts involve community representatives in government decision-making.

Table 4. Relevant studies broadly categorised according to the Aoki (2018) modified typology for understanding participation. Disaster management decision-making (rather than specifically participatory governance) methodologies used or described within the studies are shown. The table also categorises the studies according to year published (papers are alphabetically arranged within years).

		Ellemor	Gupta & Sharma	Manuel-Navarrete et al.	Beeton and Lynch	Orchiston	Orchiston et al.	Amaratunga C.A.	Espiner & Becken	Hicks et al.	Murphy et al.	Cox and Hamlen	de Andrade & Szlafsztein	Gardner	Marín et al.	Remling & Veitayaki	Blakely & Fisher	Davies et al.	Aoki	Otoara Ha'apio et al.
		2005	2006	2011	2012	2013		2014				2015				2016	2017		2018	
Types of participants	Expert administrators		✓	✓						✓				✓			✓		✓	
	Elected representatives				✓									✓					✓	
	Professional stakeholders, hired by government						✓							✓				✓	✓	
	Organised interest groups (e.g. business associations)					✓	✓							✓					✓	
	Lay stakeholders						✓							✓			✓		✓	
	Concerned general public	✓			✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	
	Diffuse public sphere									✓				✓	✓				✓	✓
Modes of recruitment	Legal mandate		✓	✓										✓			✓	✓	✓	
	Employment (professional assignment)	✓					✓			✓				✓					✓	
	Social obligation						✓		✓					✓			✓		✓	
	Targetted invitation					✓				✓				✓					✓	✓
	Open invitation	✓					✓	✓		✓	✓	✓	✓	✓		✓	✓		✓	
	Self-initiative by the participants themselves				✓									✓	✓		✓		✓	
Modes of communication	Listen as spectator	✓	✓	✓			✓			✓			✓	✓			✓		✓	
	Express preferences													✓					✓	
	Develop preferences								✓	✓				✓					✓	✓
	Aggregate preferences and propose							✓			✓	✓		✓					✓	
	Deliberate and negotiate													✓					✓	
	Deploy technique and expertise	✓			✓	✓	✓							✓	✓	✓	✓	✓	✓	
Roles of participants	Passive audience	✓	✓	✓						✓				✓			✓		✓	
	Active audience						✓			✓				✓					✓	
	Advocates							✓	✓		✓	✓		✓					✓	
	Advisors and consultants					✓							✓	✓					✓	
	Joint decision makers (co-governance)	✓			✓									✓		✓	✓		✓	✓
	Sole decision makers									✓				✓	✓		✓	✓	✓	

2.5 Thematic analysis

Thematic analysis of the 19 studies included in the present review yielded three high-level themes: Factors affecting the resilience of remote communities; Disaster management decision-making in remote communities, and Implementing participatory governance in remote communities.

2.5.1 Factors affecting the resilience of remote communities

The studies identify the widely-held belief that remote communities have a 'foundation of resilience', with residents in remote settlements identifying as 'self-reliant people whose relationship with the outdoors, which may have brought them to these locations, has equipped them with the knowledge, skills, and experience associated with resilience' (Cox & Hamlen, 2015, p. 233). In addition, members of small communities typically know the community well, and can be far more aware of demographic trends and local strengths, issues and desires than government administrators (Aoki, 2018; Cox & Hamlen, 2015; Ellemor, 2005; Espiner & Becken, 2014; Murphy et al., 2014; Orchiston, 2013).

Several factors, however, mean that those living in remote communities can also be more exposed to the impacts of hazards than the rest of the population. For example, small size and large distance from urban centres can reduce access to employment, social security, basic healthcare and other essential services (usually provided by governments), often leading to increased social and economic hardship (Murphy et al., 2014). Additionally, businesses located in remote communities are typically small, which can make them particularly vulnerable to disasters because business size is a key determinant in the uptake of resilience measures, including continuity insurance (Orchiston, 2013). Reduced business resilience can have a compounding effect on the economic resilience of remote communities. For example, short-, and in some cases long-, term unemployment can result from isolation as a result of disruption caused by disaster impacts (Chapter 3; Gardner, 2015). Further, the innate resilience of remote communities can be challenged if they are isolated following a disaster. Immediate emergency response can fail to reach isolated communities, meaning that this responsibility can fall to community members. This includes the responsibility to care for tourists, who can vastly outnumber residents and strain local resources (such as food and medical supplies) when these are unable to be replenished via distributed infrastructure (Gardner, 2015; Orchiston, 2013).

Remote indigenous communities living in recently colonised countries can be at particularly high risk. Lack of essential services and infrastructure, low incomes and high rates of physical and mental illness can be the 'result of a marginality that makes of their life a "permanent emergency"' (Bankoff, 2001, p. 25, cited in Ellemor, 2005). Historical culturally oppressive practices have perpetuated assumptions of helplessness and dependence that can make it difficult for members of these communities to act on their aspirations, and build resilience based on traditional knowledge and practices (Cox & Hamlen, 2015; Ellemor, 2005). Even in the absence of a dominant settler culture, remote indigenous communities are not always free to develop resilience measures that are based on traditional knowledge and governance arrangements (Remling & Veitayaki, 2016).

2.5.1.1 Distributed infrastructure

The studies show that increased dependence upon distributed infrastructure can have both positive and negative effects on the resilience of remote communities. Distributed infrastructure allows remote communities to reduce and overcome geographic, social, economic and/or political isolation (Gardner, 2015; Remling & Veitayaki, 2016). For example, Gardner (2015) notes that improved communications allow news and images of disasters, and even minor events, to spread fast, in principle increasing the speed of response. This news coverage can also increase the political consequences of disasters, meaning that governments can be held accountable for events in even remote communities, increasing pressure on them to improve the resilience of remote communities (Gardner, 2015). Distributed infrastructure has also provided new development opportunities, including commercial agriculture and tourism, which have further increased the resilience of remote communities (Gardner, 2015). For example, Espiner and Becken (2014) suggest that the natural attractions (such as glaciers) which enable tourism in remote communities may also increase their (post-disaster) resilience, due to the enduring desire of tourists to visit.

However, distributed infrastructure has also enabled the management and provision of essential services to become increasingly centralised (Gardner, 2015). For example, the improved road access which enables tourism often also becomes critical for the delivery of essentials, including food (Espiner & Becken, 2014). The centralisation of essential services, when combined with dependence on distributed infrastructure for ongoing business (from new development opportunities), has decreased the disaster resilience of many remote communities by substantially increasing the negative consequences of isolation (Murphy et al., 2014).

The studies establish that impacts on distributed infrastructure can be the primary cause of disaster losses at the national and regional economic scale, and confirm that remote communities have particularly low resilience to distributed infrastructure impacts (Chapter 3; Espiner & Becken, 2014; Gardner, 2015). For example, Espiner and Becken (2014) note that heavy rain in New Zealand in January 2013 washed away a bridge approach, cutting road access to Franz Josef and Fox Glacier townships for six days during the peak tourism season (the only access to the towns was via an approximately 600 km detour). Telecommunications were also cut for 36 hours by the bridge washout, compounding business interruption. Subsequently, businesses reported lost revenue in the tens of thousands of dollars, as tourism was reduced to one-third of its usual volume for six days (Espiner & Becken, 2014).

Chapter 3 reports a corresponding shift in the primary focus of the New Zealand National Infrastructure Unit from aiming to increase the resilience of infrastructure assets to ensuring essential service levels are maintained, regardless of how that service is provided. For example, the 2016 "Kaikōura" earthquake in New Zealand caused severe damage to distributed infrastructure, especially ground transportation networks, which isolated several settlements. Cross-network transportation interdependencies (i.e. air transport and boats) ensured continued regional transport and delivery of emergency supplies to isolated communities. However, this did not reduce the substantial response and recovery resources required to restore infrastructure service to isolated communities, including regional transport links (Chapter 3). While alternative means can address some shortcomings of distributed infrastructure for essential service provision in the short term, these are not effective substitutes for the distributed infrastructure required to keep remote communities effectively linked to the outside world (Gardner, 2015).

2.5.2 Disaster management decision-making in remote communities

Changes in disaster management approaches over the last two decades have seen some agencies expand the traditional focus on disaster response to include readiness, reduction and recovery. In some cases, this has led to more collaborative disaster management approaches (Chapter 3; Ellemor, 2005; Hicks et al., 2014). For example, the Rural Resilience Development Project in Canada is a collaboration between academics and the justice department which is facilitating collaborative resilience planning in remote communities (Amaratunga, 2014; Murphy et al., 2014), and Australian emergency management agencies are working more collaboratively with remote indigenous communities to build disaster resilience (Ellemor, 2005). In New Zealand, readiness, reduction, response and recovery legislation effectively mandates collaborations between emergency managers and critical infrastructure providers. This has also improved post-disaster service levels (Chapter 3) by requiring lifeline utilities to be ‘able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency’ (MCDEM, 2002, p. 40, Section 60).

All reviewed studies agree that participatory governance is required to build and maintain resilience in potentially-isolated communities (Section 2.4). Community members from remote communities need to be involved in disaster management decision-making because, if isolated, community members will need to lead immediate response efforts in the absence of authorities (Gardner, 2015; Orchiston, 2013). The need to include remote community members in disaster management decision-making has also been driven by the centralisation of essential services. The need for cost efficiency in local government has led to responsibility being shifted to community members and organisations, so that community members are increasingly relied upon, and essential to, much of the success of disaster management (Remling & Veitayaki, 2016). In addition to documenting these specific advantages participatory governance offers for remote communities, the reviewed literature is also consistent with many of the findings of the wider participatory governance literature, showing that participatory governance can be advantageous for communities in general, and inform better decision-making in government and the private sector (Section 2.2.3).

2.5.3 Implementing participatory governance in remote communities

The literature also identifies several factors that make participatory approaches difficult to implement, despite the established benefits of participation (Section 2.2.3). Members of some indigenous communities in Australia and Fiji, for example, will only adopt disaster management initiatives if they have capacity to do so and are not concerned about more pressing development issues (Ellemor, 2005; Remling & Veitayaki, 2016). Capacity to participate can be particularly limited in remote communities (Aoki, 2018; Ellemor, 2005), where community members are often time-poor because they need to generate income, often from unstable sources such as tourism and farming, or are struggling with development issues, including poor physical and mental health levels (Amaratunga, 2014; Ellemor, 2005). Moreover, as already discussed (Section 2.5.1), Orchiston (2013) finds that businesses within remote communities have particularly low resilience because they are often too small to invest in resilience. The capacity of the community to invest in resilience and to contribute in participatory processes must be ascertained before implementing participatory decision-making approaches in remote communities.

Ellemor (2005) and Amaratunga (2014) argue that when engaging with indigenous communities to design disaster management initiatives it is critical to first understand what constitutes “normal” for that community, so that the converse of a disaster can be understood. While these studies are concerned with indigenous communities in particular, the importance of recognising that only community members are qualified to understand and communicate what is “normal” for the relevant community is also consistent with the emphasis in participatory governance literature on tailoring methodologies to specific contexts.

Another key factor is the extent of community trust in the process. To be effective, disaster management “solutions” must be preferred by the community (Remling & Veitayaki, 2016). This factor is more influential than whether a solution is objectively “better” or “worse” in theory, because for a disaster management initiative to succeed and be sustainable, the community must adopt and take ownership of the initiative (Remling & Veitayaki, 2016). This is particularly relevant in remote communities, given that community members are essential to implementing disaster management here (Section 2.5.2). Community members are unlikely to implement a planned “solution” if they do not agree with it, particularly if the disaster results in isolation from the authorities who planned (to implement) it (Remling & Veitayaki, 2016). Again, this is critical for indigenous communities, where trust in government and other authorities is typically low as a result of historical and current cultural oppression (Ellemor, 2005). Involvement in the process of participatory community resilience planning can be even more valuable in terms of trust building than the planning solutions (Murphy et al., 2014).

Increasing the amount communities participate in decision-making is a consistent concern in the studies, which include both community-led participation, and participatory processes instituted by government agencies (Aoki, 2018; Gardner, 2015; Orchiston, 2013). All the studies agree with the need, identified by Ackerman (2004), to involve both government and communities. Participatory disaster resilience-building in remote communities is less likely to be successful when it occurs without government involvement, as is government decision-making without participation (Section 2.5.2). To implement disaster resilience initiatives, jurisdictional authority at the local, regional and national level may be required, as might substantial resources (including funding), making it difficult for communities to implement disaster management initiatives alone (Aoki, 2018; Cox & Hamlen, 2015; Gardner, 2015; Murphy et al., 2014; Orchiston, 2013; Otoara Ha’apio et al., 2018).

The community-led participatory approaches documented in the identified literature are tailored for the relevant remote communities. These have focussed on collaboration to reduce the individual level of effort required, which in turn can enable participation. For example, Orchiston (2013) observes community-based disaster planning is promising for small businesses with limited capacity to invest in resilience, and Amaratunga (2014), Cox and Hamlen (2015), and Murphy et al. (2014) document the facilitation of the Canadian Rural Disaster Resilience Project (RDRP). The RDRP aims to increase the resilience of remote indigenous communities in Canada by allowing them to communicate with and learn from each other through a “virtual community of practice”.

Government-led disaster management approaches have moved towards participatory governance as part of the expanding focus of disaster management agencies to include readiness, reduction and recovery, alongside response. The identified literature provides examples of this shift, including initiatives enabled by researchers collaborating with decision-makers to strengthen existing disaster management decision-making (Amaratunga, 2014; Hicks et al., 2014). Several studies also report that promotional activities by dedicated and respected community members are essential to the success of participatory decision-making (Aoki, 2018; Orchiston, 2013; Remling & Veitayaki, 2016). Community champions are not only well placed to encourage community participation, they are also well placed to communicate to other decision-makers what is “normal” and needed for the relevant community, particularly in the case of indigenous communities, and in this way advocate for the specific needs of remote communities. For this reason, Ellemor (2005) calls for the employment of indigenous community members within relevant government structures to enable collaborative planning, grow mutual trust and understanding between communities and government agencies, and to build community capacity and resourcing. Building knowledge and enhancing skill competency levels within remote indigenous communities are key themes within government-led participatory disaster management approaches, including the provision of education and training provided to community members by disaster management agencies, and the use of bridging organisations, including universities and NGOs (Amaratunga, 2014; Murphy et al., 2014). Education can substantially contribute to the cultivation of a sustainable participation culture (Aoki, 2018; Remling & Veitayaki, 2016). More broadly, collaborative efforts have been found to result in gradual improvements in relationships between disaster management agencies and indigenous communities (Ellemor, 2005; Hicks et al., 2014).

The Aoki (2018) case study of a participatory governance recovery rebuild initiative in Onagawa is the only example in the reviewed literature of community members and government experts sharing decision-making responsibilities. Aoki (2018) finds that participation levels and engagement were increased by the use of multiple methodologies within one overarching process. Where “all or nothing” participation options can reduce participation, the use of multiple methodologies provided a range of options, allowing people with different capacities to choose to participate through the methodology which suited them best (Aoki, 2018). For example, public opinion was widely canvassed through a series of public briefings which supplemented a series of working group meetings which involved more intense levels of participation. Aoki (2018) found that the public briefings helped to increase participation, allowing participation from people with limited capacity to participate, and were especially helpful for those with mental and physical hardships post-disaster. Widely canvassing public opinion through public briefings also added legitimacy to the overall process by verifying that community input had been consistent with wider community views (e.g. not excluding the views of those who had limited capacity to participate in the working group) and by helping to confirm that the government development vision was consistent with the views of the wider community.

While choosing a disaster management "solution" that is preferred by the community is necessary, as Remling and Veitayaki (2016) establish, Aoki (2018) also notes that community preference alone is not sufficient. For example, in a participatory recovery process in Kesennuma, Japan, the winning design from an open competition for reconstruction plans, chosen by the majority of a judging panel consisting of three urban planning experts, the mayor, and 36 ordinary citizens, 'was later found to be neither fiscally nor technically feasible' (Aoki, 2018, p. 227). Such outcomes can erode trust in participatory processes and jeopardise future appetite for involvement. Aoki (2018) finds that appropriately sequencing the involvement of technical experts (early on) would have ensured that only feasible designs were considered by the judging panel in Kesennuma. These findings are highly applicable to other remote communities, which have similarly limited capacity to take part in participatory processes, and which are highly dependent upon (highly-technical) distributed infrastructure (Chapter 3; Espiner & Becken, 2014; Gardner, 2015; Orchiston, 2013).

Finally, the literature confirms that the specific composition of the relevant community can have a substantial effect on the success of participatory processes. The typically tight-knit character of remote communities in Japan and New Zealand, for example, has been found to enable participatory governance, with Orchiston (2013), Espiner and Becken (2014) and Aoki (2018) all reporting participatory disaster management processes that involve remote communities and are led by local businesses. Aoki (2018, p. 235) also found that strong place attachment and strong social connections, reinforced by everyday interactions between community members, including those from the private and government sectors, led to 'a strong collective sense of survival' which 'encouraged people to remain relatively understanding and willing to compromise and work together towards a consensus, rather than resorting to conflict; this compromise was necessary to keep [participatory governance] going' during the post-tsunami rebuild of Onagawa. This suggests that participatory approaches may not only be more necessary in remote communities, but that in some cases, they may also be easier to achieve as community members can have more willingness to participate. For example, Aoki (2018, p. 235) notes that education was actually requested by community members during the Onagawa participatory process as they 'came to believe that they should not keep asking the government to do things for them, but should play a more proactive role'.

However, the historical oppression and marginalisation of remote indigenous communities in Australia and Canada has resulted in an understandably deep mistrust of government agencies, and a corresponding tendency on the part of often well-intentioned government administrators to ignore and/or devalue the capacity for resilience conferred by traditional knowledge and cultural practices, instead characterising indigenous community members as passive victims (Ellemor, 2005). This means that the need for more holistic, inclusive and participatory approaches to disaster management is at its most extreme in remote indigenous communities, where the composition of both the community and government agencies makes such approaches much more difficult to achieve. Acknowledging recent modest improvements in relations between emergency management agencies and remote indigenous communities, Ellemor (2005) still finds that much more engagement is needed. Particularly, Ellemor (2005) finds that the employment of indigenous community members in emergency management roles would add the most value. This approach has the potential to increase incomes in economically challenged communities, increase community trust in government agencies, build community capacity to contribute to key disaster resilience decision-making, and raise awareness inside government agencies of the needs and value offered by traditional knowledge and practices (Ellemor, 2005).

2.6 Discussion

The systematic review methodology was useful for identifying relevant publications and providing a degree of oversight into research in this emerging, dispersed and interdisciplinary field. Bringing together a range of articles concerning the disaster resilience of remote communities (n = 19 articles) indicates that the resulting field is broadly characterised by the conceptual divide between evolutionary and equilibrist resilience identified by White and O'Hare (2014) (Section 1). Studies are either largely focussed on involving communities in participatory approaches to build social resilience, or primarily concerned with economic and/or infrastructure resilience.

There is also considerable evidence of softening across this divide. Studies concerned with building sociocultural resilience by reducing existing inequities also acknowledge the role of infrastructure (Murphy et al., 2014; Remling & Veitayaki, 2016), while those primarily concerned with infrastructure and/or economic resilience similarly acknowledge the importance of socio-cultural resilience (Chapter 3; Espiner & Becken, 2014; Gardner, 2015; Orchiston, 2013). The strongest evidence of this change is common ground around the consensus concerning the promise of participatory methodologies when it comes to building resilience in remote communities. Although not all studies are directly concerned with the involvement of community members in disaster management decision-making, all agree that such involvement is particularly necessary for remote communities.

Large distance from urban centres, small size and cost efficiencies effected through centralisation mean that community members in remote communities are likely to be responsible for immediate response efforts (Gardner, 2015; Orchiston, 2013). Remote communities often have a tight-knit character, with strong connections between community members, and high levels of place attachment (Aoki, 2018; Cox & Hamlen, 2015; Ellemor, 2005; Espiner & Becken, 2014; Murphy et al., 2014; Orchiston, 2013). These provide incentives for community members to participate and compromise for the benefit of the relevant community and its environs, meaning that participatory approaches may not only be more necessary in remote communities, but that in some cases, they may also be easier to achieve (Aoki, 2018; Espiner & Becken, 2014; Orchiston, 2013).

However, community members are unlikely to participate if they do not have trust in the process and the people leading it. Even if community members do participate, without trust, community members will not take the ownership that is essential for the disaster management initiative to succeed and be sustainable (Remling & Veitayaki, 2016). Trust has to be earned, as is starkly exemplified in remote Australian and Canadian indigenous communities, where particularly low levels of trust in government agencies are the legacy of oppressive colonial practices (Cox & Hamlen, 2015; Ellemor, 2005). Recent attempts to move towards more collaborative engagement with some of these communities have resulted in gradual improvements in relationships with disaster management agencies (Ellemor, 2005; Hicks et al., 2014; Murphy et al., 2014). Far more mutual trust and understanding is required if indigenous communities are to be empowered to take ownership of such collaborations (Ellemor, 2005). Ellemor (2005) argues that this might be best achieved through the employment of indigenous community members in local emergency management positions. Locally resident government representatives are likely to identify and be identified as local community members, enabling trust in the participatory process (Aoki, 2018).

The employment of local community members would also contribute significantly to the low incomes typical of remote indigenous communities (Ellemor, 2005). Again, this is illustrative of a wider issue affecting the capacity of community members to participate, or invest, in disaster impact reduction efforts. Those living in remote communities are typically time-poor when compared with those living in urban areas due to the need to generate income, and/or the difficulties of living in communities with poor physical and mental health levels (Aoki, 2018; Ellemor, 2005; Remling & Veitayaki, 2016). Employment of local community members in disaster resilience and emergency response roles would increase the capacity to contribute by supplementing income and dedicating the time of community members to improving the resilience of the community (Ellemor, 2005).

To accommodate the diverse range of capacities to participate that are typical of any community, the design, implementation and possible outcomes of participation methodologies need to be informed by and tailored to the relevant specific climatic, environmental, social, economic, and political context (Remling & Veitayaki, 2016). Appropriately tailoring participation approaches can increase participation levels, which can add legitimacy to the process: first, by verifying that community input through more intense participation methodologies is broadly consistent with wider community views expressed through less intense participation methodologies (e.g. not excluding the views of those who had limited capacity and so could not participate in the chosen methodology); and second, by helping to confirm that the (resulting) government development vision is consistent with the views of the wider community (Aoki, 2018). Appropriately sequencing participation methodologies and ensuring that these are transparent is also critical to the success of participatory processes. Sequencing participation allows different stakeholder groups to participate more intensely at different stages during the overall process, focussing on relevant areas. This helps to ensure that “solutions” which are not technically or financially feasible and so can undermine trust, are not proposed. However, “black box” decision-making without community participation in parts of the process, can leave community members unsure how decisions have been made and so can also undermine trust

(Aoki, 2018; Remling & Veitayaki, 2016). These issues can be avoided by enabling the participation of community members in all aspects of the process, as long as the technical and government expertise concerning the feasibility of collaborative outcomes is appropriately sequenced and weighted (Aoki, 2018). Sequencing participation also helps to further overcome barriers to participation by reducing the time commitment required from each stakeholder group (Aoki, 2018).

The studies also highlight the key role that increased dependence upon distributed infrastructure can play in the resilience of remote communities. Distributed infrastructure allows remote communities to dramatically reduce, and in some cases overcome, geographic, social, economic and political isolation (Gardner, 2015; Remling & Veitayaki, 2016). However, dependence on distributed infrastructure for business and essential services and supplies (including food and medical supplies) has also decreased the disaster resilience of remote communities. Damage to distributed infrastructure networks, including that caused by natural hazards, can result in the partial and sometimes complete loss of a given community's essential services for considerable periods of time, at substantial social as well as economic cost (Chapter 3; Espiner & Becken, 2014; Gardner, 2015).

The focus of research and practical initiatives aiming to increase distributed infrastructure resilience has shifted, with increased awareness of the social and economic consequences of essential services loss, towards increasing prioritisation of service provision over maintaining infrastructure assets. However, the findings of this review suggest that the resilience of remote communities is likely to be substantially enhanced by using more inclusive participatory planning approaches that involve government decision-makers, distributed infrastructure providers and community members in sustained collaborative programmes that bring together community, technical and government knowledge to build a wider picture of disaster resilience and potential mitigative "solutions". Aoki (2018) offers a particularly useful template for such approaches. Her typology allows for the careful management of stakeholder engagement and potential power imbalances, and the sequencing of expert technical and government input is particularly applicable in relation to infrastructure resilience. Further, both Aoki (2018) and Ellemor (2005) discuss the advantages of the employment of community members in relevant organisations and government agencies. This would likely further increase the mutual trust and understanding required for effective participation, while also building capacity to contribute by supplementing income and dedicating the time of community members to improving the resilience of the relevant remote community, as well as raising awareness inside government agencies of the needs and value offered by traditional knowledge and practices (Ellemor, 2005).

2.7 Conclusions

The research field systematically identified in this study, concerned with the disaster resilience of remote communities, is relatively sparse, dispersed and recent, so more research is needed to test, corroborate and expand these findings. The oversight this review provides indicates a consistent focus across disciplines and countries of origin on the need to involve more than one sector, and in particular community members, in decision-making to increase the resilience of remote communities. The prevalence of studies focussed on community-led planning in remote indigenous communities in Australia and Canada reflects the marginalisation of these communities as a result of recent colonisation, while the surprising absence of publications focussed on the disaster resilience of remote Māori communities, despite New Zealand's recent history of colonisation and official status as a bicultural nation, indicates an urgent need for research in this area. Alongside this shared emphasis on the need for and importance of, inclusive participatory resilience-building approaches, the literature emphasises the role played by distributed infrastructure in the resilience of remote communities, focussing on the decreased resilience of remote communities to abrupt isolation as disaster damage to distributed infrastructure can result in the partial and sometimes complete loss of essential services, at substantial social, as well as economic, cost.

The reviewed literature does not, however, feature any studies that focus on bringing infrastructure providers and remote community members together to participate in disaster management decision-making. This omission is consistent with the disciplinary normative tendency, identified by White and O'Hare (2014), to apply the term "resilience" either to preserve, maintain and restore the built environment (including infrastructure), or to inclusive approaches to reducing the social inequities that inhibit resilience at local levels. The convergence evident in the reviewed literature towards participatory resilience-building initiatives is likely to have been driven, at least in part, by recognition of the decreased resilience of remote communities to isolation, resulting from increased dependence on distributed infrastructure. It is timely, then, to call for research that takes this convergence further, to incorporate decision-making concerning the provision of essential services into disaster impact reduction initiatives focussed on building socio-cultural resilience.

The design of participatory governance processes has been found to be critical to their success. Aoki's (2018) findings concerning the importance of multiple methodologies and the use of sequencing to ensure that resilience solutions are feasible as well as preferred by communities offer a promising foundation for participatory governance approaches. Rising disaster losses and the ongoing centralisation of essential services make the need for this research urgent, as well as timely.

2.8 References

Ackerman, J 2004, 'Co-governance for accountability: beyond "exit" and "voice"', *World Development,* vol. 32, no. 3, pp. 447-463.

Amaratunga, CA 2014, 'Building community disaster resilience through a virtual community of practice (VCOP)', *International Journal of Disaster Resilience in the Built Environment,* vol. 5, no. 1, pp. 66-78.

Aoki, N 2018, 'Sequencing and combining participation in urban planning: The case of tsunami-ravaged Onagawa Town, Japan', *Cities,* vol. 72, pp. 226-236.

Arnstein, SR 1969, 'A ladder of citizen participation', *Journal of the American Institute of planners,* vol. 35, no. 4, pp. 216-224.

Beeton, RJ & Lynch, AJJ 2012, 'Most of nature: a framework to resolve the twin dilemmas of the decline of nature and rural communities', *Environmental Science & Policy,* vol. 23, pp. 45-56.

Beierle, TC 2002, 'The quality of stakeholder-based decisions', *Risk analysis,* vol. 22, no. 4, pp. 739-749.

Bishop, P, Hines, A & Collins, T 2007, 'The current state of scenario development: an overview of techniques', *Foresight,* vol. 9, no. 1, pp. 5-25.

Blackstock, KL, Kelly, GJ & Horsey, BL 2007, 'Developing and applying a framework to evaluate participatory research for sustainability', *Ecological economics,* vol. 60, no. 4, pp. 726-742.

Blakely, EJ & Fisher, PM 2017, 'Assessing non-metro recovery across two continents: issues and limitations', *Disasters,* vol. 41, no. 3, pp. 487-504.

Bohensky, E, Butler, J & Mitchell, D 2011a, 'Scenarios for knowledge integration: exploring ecotourism futures in Milne Bay, Papua New Guinea', *Journal of Marine Biology,* vol. 2011, p. 11.

Bohensky, E, Butler, JRA, Costanza, R, Bohnet, I, Delisle, A, Fabricius, K, Gooch, M, Kubiszewski, I, Lukacs, G, Pert, P & Wolanski, E 2011b, 'Future makers or future takers? A scenario analysis of climate change and the Great Barrier Reef', *Global Environmental Change,* vol. 21, no. 3, pp. 876-893.

Bohnet, IC 2010, 'Integrating social and ecological knowledge for planning sustainable land- and sea-scapes: experiences from the Great Barrier Reef region, Australia', *Landscape Ecology,* vol. 25, no. 8, pp. 1201-1218.

Bressler, GH, Jennex, ME & Frost, EG 2012, 'X24 Mexico: Stronger Together', *Proceedings of the 9th International ISCRAM Conference*, Vancouver, Canada, p. 5.

Broad, K, Pfaff, A, Taddei, R, Sankarasubramanian, A, Lall, U & de Souza Filho, FdA 2007, 'Climate, stream flow prediction and water management in northeast Brazil: societal trends and forecast value', *Climatic Change,* vol. 84, no. 2, pp. 217-239.

Bruneau, M, Chang, SE, Eguchi, RT, Lee, GC, O'Rourke, TD, Reinhorn, AM, Shinozuka, M, Tierney, K, Wallace, WA & Von Winterfeldt, D 2003, 'A framework to quantitatively assess and enhance the seismic resilience of communities', *Earthquake spectra,* vol. 19, no. 4, pp. 733-752.

Buldyrev, SV, Parshani, R, Paul, G, Stanley, HE & Havlin, S 2010, 'Catastrophic cascade of failures in interdependent networks', *Nature,* vol. 464, no. 7291, pp. 1025-1028.

Burton, P, Goodlad, R, Croft, J, Abbott, J, Hastings, A, Macdonald, G & Slater, T 2004, *What works in community involvement in area-based initiatives? A systematic review of the literature*, Home Office Online Report 53, UK, 4.

Butler, JRA, Bohensky, EL, Suadnya, W, Yanuartati, Y, Handayani, T, Habibi, P, Puspadi, K, Skewes, TD, Wise, RM, Suharto, I, Park, SE & Sutaryono, Y 2016, 'Scenario planning to leap-frog the Sustainable Development Goals: An adaptation pathways approach', *Climate Risk Management,* vol. 12, pp. 83-99.

Cannon, T 2014, *'Why do we pretend there is 'Community'? Problems of community based-adaptation (CBA) and community based disaster risk reduction (CBDRR)', IDS Povertics, Institute of Development Studies (UK)*, viewed 27/07/18, http://vulnerabilityandpoverty.blogspot.com/2014/04/why-do-we-pretend-there-is-community.html.

Cauffman, S 2015, *Community Resilience Planning Guide for Buildings and Infrastructure Systems, Vol. 1*, NIST Special Publication 1190, U.S. Department of Commerce, United States, vol. 1.

Cavallo, EA & Noy, I 2009, *The Economics of Natural Disasters: A Survey*, IDB Working Paper Series, Inter-American Development Bank, IDB-WP-124.

Centre for Advanced Engineering 1997, *Risks & Realities: A Multi-disciplinary Approach to the Vulnerability of Lifelines to Natural Hazards*, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand.

Chang, SE 2014, 'Infrastructure resilience to disasters', *The Bridge,* vol. 44, no. 3, pp. 36-41.

Chang, SE, McDaniels, TL, Mikawoz, J & Peterson, K 2007, 'Infrastructure failure interdependencies in extreme events: power outage consequences in the 1998 Ice Storm', *Natural Hazards,* vol. 41, no. 2, pp. 337-358.

Cooke, B 2004, 'Rules of thumb for participatory change agents', *Participation: From tyranny to transformation*, pp. 42-55.

Cooke, B & Kothari, U 2001, *Participation: The new tyranny?*, ZED books, London and New York.

Cornwall, PA 2011, *The participation reader*, ZED Books, London and New York.

Cosgrove, WJ & Rijsberman, FR 2000, *World water vision: making water everybody's business*, Routledge, World Water Council, Paris, France.

Cox, RS & Hamlen, M 2015, 'Community disaster resilience and the rural resilience index', *American Behavioral Scientist,* vol. 59, no. 2, pp. 220-237.

de Andrade, MMN & Szlafsztein, CF 2015, 'Community participation in flood mapping in the Amazon through interdisciplinary methods', *Natural Hazards,* vol. 78, no. 3, pp. 1491-1500.

Deligne, NI, Blake, DM, A.J., D, Grace, ES, Hayes, J, Potter, S, Stewart, C, Wilson, G & Wilson, TM 2015, 'Economics of Resilient Infrastructure Auckland Volcanic Field Scenario', *ERI Research Report,* vol. 2015, no. 3, p. 151.

Díez, MA, Etxano, I & Garmendia, E 2015, 'Evaluating participatory processes in conservation policy and governance: lessons from a Natura 2000 pilot case study', *Environmental Policy and Governance,* vol. 25, no. 2, pp. 125-138.

Dougill, A, Fraser, E, Holden, J, Hubacek, K, Prell, C, Reed, M, Stagl, S & Stringer, L 2006, 'Learning from doing participatory rural research: lessons from the Peak District National Park', *Journal of Agricultural Economics,* vol. 57, no. 2, pp. 259-275.

Duane, TP 1999, *Shaping the Sierra: Nature, culture, and conflict in the changing West*, University of California Press.

Ellemor, H 2005, 'Reconsidering emergency management and indigenous communities in Australia', *Global Environmental Change Part B: Environmental Hazards,* vol. 6, no. 1, pp. 1-7.

Espiner, S & Becken, S 2014, 'Tourist towns on the edge: Conceptualising vulnerability and resilience in a protected area tourism system', *Journal of Sustainable Tourism,* vol. 22, no. 4, pp. 646-665.

Fenwick, A 2012, *The Value of Lifeline Seismic Risk Mitigation in Christchurch: Summary Report, June 2012*, New Zealand Lifelines.

Fiji Bureau of Statistics n.d., *Government of Fiji: Regional population mapping*, viewed 5/10/18, https://www.statsfiji.gov.fj/index.php/population-gis-maps.

Fischer, F 2000, *Citizens, experts, and the environment: The politics of local knowledge*, Duke University Press.

Ford, JD, Berrang-Ford, L & Paterson, J 2011, 'A systematic review of observed climate change adaptation in developed nations', *Climatic Change,* vol. 106, no. 2, pp. 327-336.

Fritsch, O & Newig, J 2012, 'Participatory governance and sustainability: findings of a meta-analysis of stakeholder involvement in environmental decision making', in E Brousseau, T Dedeurwaerdere & B Siebenhüner (eds), *Reflexive governance for global public goods*, The MIT Press, pp. 181-203.

Fung, A 2006, 'Varieties of participation in complex governance', *Public administration review,* vol. 66, no. s1, pp. 66-75.

Gaillard, J-C & Mercer, J 2013, 'From knowledge to action: Bridging gaps in disaster risk reduction', *Progress in human geography,* vol. 37, no. 1, pp. 93-114.

Gardner, JS 2015, 'Risk complexity and governance in mountain environments', in FP Urbano (ed.), *Risk governance: The Articulation of Hazard, Politics and Ecology*, Springer, Dordrecht, pp. 349-371.

Giovinazzi, S, Wilson, T, Davis, C, Bristow, D, Gallagher, M, Schofield, A, Villemure, M, Eidinger, J & Tang, A 2011, 'Lifelines performance and management following the 22 February 2011 Christchurch earthquake, New Zealand: highlights of resilience', *Bulletin of the New Zealand Society for Earthquake Engineering,* vol. 44, no. 4, pp. 402-417.

Grabowski, Z, Matsler, A, Thiel, C, McPhillips, L, Hum, R, Bradshaw, A, Miller, T & Redman, C 2017, 'Infrastructures as socio-eco-technical systems: Five considerations for interdisciplinary dialogue', *Journal of Infrastructure Systems,* vol. 23, no. 4, pp. 1-9.

Greenwood, DJ, Whyte, WF & Harkavy, I 1993, 'Participatory action research as a process and as a goal', *Human relations,* vol. 46, no. 2, pp. 175-192.

Gupta, M & Sharma, A 2006, 'Compounded loss: the post tsunami recovery experience of Indian island communities', *Disaster Prevention and Management: An International Journal,* vol. 15, no. 1, pp. 67-78.

Haddaway, NR & Pullin, AS 2014, 'The Policy Role of Systematic Reviews: Past, Present and Future', *Springer Science Reviews,* vol. 2, no. 1, pp. 179-183.

Halevi, G, Moed, H & Bar-Ilan, J 2017, 'Suitability of Google Scholar as a source of scientific information and as a source of data for scientific evaluation-Review of the Literature', *Journal of Informetrics,* vol. 11, no. 3, pp. 823-834.

Hansman, RJ, Magee, C, De Neufville, R, Robins, R & Roos, D 2006, 'Research agenda for an integrated approach to infrastructure planning, design and management', *International Journal of Critical Infrastructures,* vol. 2, no. 2-3, pp. 146-159.

Hicks, A, Barclay, J, Simmons, P & Loughlin, S 2014, 'An interdisciplinary approach to volcanic risk reduction under conditions of uncertainty: a case study of Tristan da Cunha', *Natural Hazards and Earth System Science,* vol. 14, no. 7, pp. 1871-1887.

Hill, R, Williams, KJ, Pert, PL, Robinson, CJ, Dale, AP, Westcott, DA, Grace, RA & O'Malley, T 2010, 'Adaptive community-based biodiversity conservation in Australia's tropical rainforests', *Environmental Conservation,* vol. 37, no. 1, pp. 73-82.

Howard, TM 2018, 'Balancing the see-saw of natural resource governance: the interaction of legislation, policy and practice in four Australian participatory processes', *Australasian Journal of Environmental Management,* vol. 25, no. 2, pp. 174-192.

IEM 2013, *Ensuring Compliance In An All-Hazard Mitigation Plan*, viewed 25/07/18, http://www.iem.com/case-studies/hurricane-pam.

Jones, LM & Benthien, M 2011, 'Preparing for a "Big One": the great southern California ShakeOut', *Earthquake Spectra,* vol. 27, no. 2, pp. 575-595.

Jurgilevich, A, Räsänen, A, Groundstroem, F & Juhola, S 2017, 'A systematic review of dynamics in climate risk and vulnerability assessments', *Environmental Research Letters,* vol. 12, no. 1, p. 15.

Kahane, A 2012, *Transformative scenario planning: Working together to change the future*, Berrett-Koehler Publishers.

Kirmayer, LJ, Dandeneau, S, Marshall, E, Phillips, MK & Williamson, KJ 2011, 'Rethinking Resilience from Indigenous Perspectives', *The Canadian Journal of Psychiatry,* vol. 56, no. 2, pp. 84-91.

Kok, K, Biggs, RO & Zurek, M 2007, 'Methods for developing multiscale participatory scenarios: insights from southern Africa and Europe', *Ecology and Society,* vol. 12, no. 1, p. 16.

Koontz, TM 2005, 'We finished the plan, so now what? Impacts of collaborative stakeholder participation on land use policy', *Policy studies journal,* vol. 33, no. 3, pp. 459-481.

Kothari, U 2001, 'Power, knowledge and social control in participatory development', in B Cooke & U Kothari (eds), *Participation: The New Tyranny?*, ZED books, London and New York, pp. 139-152.

Macnaghten, P & Jacobs, M 1997, 'Public identification with sustainable development: Investigating cultural barriers to participation', *Global Environmental Change,* vol. 7, no. 1, pp. 5-24.

Manuel-Navarrete, D, Pelling, M & Redclift, M 2011, 'Critical adaptation to hurricanes in the Mexican Caribbean: development visions, governance structures, and coping strategies', *Global Environmental Change,* vol. 21, no. 1, pp. 249-258.

Marin, A, Bodin, Ö, Gelcich, S & Crona, B 2015, 'Social capital in post-disaster recovery trajectories: Insights from a longitudinal study of tsunami-impacted small-scale fisher organizations in Chile', *Global Environmental Change,* vol. 35, pp. 450-462.

Maskrey, A 2011, 'Revisiting community-based disaster risk management', *Environmental Hazards,* vol. 10, no. 1, pp. 42-52.

McDaniels, TL, Chang, SE, Hawkins, D, Chew, G & Longstaff, H 2015, 'Towards disaster-resilient cities: an approach for setting priorities in infrastructure mitigation efforts', *Environment Systems and Decisions,* vol. 35, no. 2, pp. 252-263.

MCDEM 2002, *Civil Defence Emergency Management Act 2002*, New Zealand Government Ministry of Civil Defence & Emergency Management, Wellington.

Meho, LI & Yang, K 2007, 'Impact of data sources on citation counts and rankings of LIS faculty: Web of Science versus Scopus and Google Scholar', *Journal of the Association for Information Science and Technology,* vol. 58, no. 13, pp. 2105-2125.

Millennium Assessment Board 2005, *Millennium Ecosystem Assessment*, Island Press, Washington, DC: New Island.

Murphy, BL, Anderson, GS, Bowles, R & Cox, RS 2014, 'Planning for disaster resilience in rural, remote, and coastal communities: Moving from thought to action', *Journal of emergency management,* vol. 12, no. 1, p. 16.

National Infrastructure Unit 2015, *The Thirty Year New Zealand Infrastructure Plan 2015*, New Zealand Government, Wellington, New Zealand.

Nelson, N & Wright, S 1995, *Power and Participatory Development: Theory and Practice*, ITDG Publishing.

Newig, J 2007, 'Does public participation in environmental decisions lead to improved environmental quality?: towards an analytical framework', *Communication, Cooperation, Participation (International Journal of Sustainability Communication),* vol. 1, no. 1, pp. 51-71.

Orchiston, C 2013, 'Tourism business preparedness, resilience and disaster planning in a region of high seismic risk: The case of the Southern Alps, New Zealand', *Current Issues in Tourism,* vol. 16, no. 5, pp. 477-494.

Orchiston, C, Manuel, C, Coomer, M, Becker, J & Johnston, D 2013, 'The 2009 New Zealand West Coast ShakeOut: Improving earthquake preparedness in a region of high seismic risk', *Australasian Journal of Disaster and Trauma Studies,* vol. 2013, no. 2, pp. 56-61.

Orchiston, C, Mitchell, J, Wilson, T, Langridge, R, Davies, T, Bradley, B, Johnston, D, Davies, A, Becker, J & McKay, A 2018, 'Project AF8: developing a coordinated, multi-agency response plan for a future great Alpine Fault earthquake', *New Zealand Journal of Geology and Geophysics*, pp. 1-14.

Oteros-Rozas, E, Martn-Lpez, B, Lpez, CA, Palomo, I & Gonzlez, JA 2013, 'Envisioning the future of transhumant pastoralism through participatory scenario planning: A case study in Spain', *Rangeland Journal,* vol. 35, no. 3, pp. 251-272.

Otoara Ha'apio, M, Wairiu, M, Gonzalez, R & Morrison, K 2018, 'Transformation of rural communities: lessons from a local self-initiative for building resilience in the Solomon Islands', *Local Environment*, pp. 1-14.

Palomo, I, Martín-López, B, López-Santiago, C & Montes, C 2011, 'Participatory scenario planning for protected areas management under the ecosystem services framework: the Doñana social-ecological system in southwestern Spain', *Ecology and Society,* vol. 16, no. 1, p. 33.

Pearce, L 2003, 'Disaster management and community planning, and public participation: how to achieve sustainable hazard mitigation', *Natural hazards,* vol. 28, no. 2-3, pp. 211-228.

Pescaroli, G & Alexander, D 2016, 'Critical infrastructure, panarchies and the vulnerability paths of cascading disasters', *Natural Hazards,* vol. 82, no. 1, pp. 175-192.

Peterson, GD, Beard Jr, TD, Beisner, BE, Bennett, EM, Carpenter, SR, Cumming, GS, Dent, CL & Havlicek, TD 2003, 'Assessing future ecosystem services: A case study of the Northern Highlands Lake District, Wisconsin', *Conservation Ecology,* vol. 7, no. 3, p. 24.

Plieninger, T, Bieling, C, Ohnesorge, B, Schaich, H, Schleyer, C & Wolff, F 2013, 'Exploring futures of ecosystem services in cultural landscapes through participatory scenario development in the Swabian Alb, Germany', *Ecology and Society,* vol. 18, no. 3, p. 16.

Ravera, F, Hubacek, K, Reed, M & Tarrasón, D 2011, 'Learning from experiences in adaptive action research: a critical comparison of two case studies applying participatory scenario development and modelling approaches', *Environmental Policy and Governance,* vol. 21, no. 6, pp. 433-453.

Reed, MS 2008, 'Stakeholder participation for environmental management: a literature review', *Biological conservation,* vol. 141, no. 10, pp. 2417-2431.

Reed, MS, Dougill, AJ & Baker, TR 2008, 'Participatory indicator development: what can ecologists and local communities learn from each other', *Ecological Applications,* vol. 18, no. 5, pp. 1253-1269.

Reed, MS, Fraser, ED & Dougill, AJ 2006, 'An adaptive learning process for developing and applying sustainability indicators with local communities', *Ecological economics,* vol. 59, no. 4, pp. 406-418.

Reed, MS, Kenter, J, Bonn, A, Broad, K, Burt, T, Fazey, I, Fraser, E, Hubacek, K, Nainggolan, D & Quinn, C 2013, 'Participatory scenario development for environmental management: A methodological framework illustrated with experience from the UK uplands', *Journal of Environmental Management,* vol. 128, pp. 345-362.

Remling, E & Veitayaki, J 2016, 'Community-based action in Fiji's Gau Island: a model for the Pacific?', *International Journal of Climate Change Strategies and Management,* vol. 8, no. 3, pp. 375-398.

Richards, C, Carter, C & Sherlock, K 2004, *Practical approaches to participation*, Socio-Economic Reserach Group (SERG) Policy Brief Number 1, Macaulay Institute.

Robinson, TR, Buxton, R, Wilson, TM, Cousins, WJ & Christophersen, AM 2015, 'Multiple infrastructure failures and restoration estimates from an Alpine Fault earthquake: Capturing modelling information for MERIT', *ERI Research Report,* vol. 2015, no. 4, p. 89.

Rowe, G & Frewer, LJ 2005, 'A typology of public engagement mechanisms', *Science, technology & human values,* vol. 30, no. 2, pp. 251-290.

SARRAH n.d., *Services for Australian Rural and Remote Allied Health: Defining Remote and Rural Context*, viewed 5/10/18, https://sarrah.org.au/content/defining-remote-and-rural-context.

Spector, S, Cradock-Henry, NA, Beaven, S & Orchiston, C 2018, 'Characterizing rural resilience in Aotearoa-New Zealand: a systematic review', *Regional Environmental Change*, pp. 1-15.

Statistics Canada n.d., *Government of Canada: Data and Definitions*, viewed 5/10/18, https://www150.statcan.gc.ca/n1/pub/21-006-x/2008008/section/s2-eng.htm.

Stats NZ n.d., *New Zealand Government: Defining Urban and Rural*, viewed 5/10/18, http://archive.stats.govt.nz/browse_for_stats/Maps_and_geography/Geographic-areas/urban-rural-profile/defining-urban-rural-nz.aspx.

Stringer, LC, Dougill, AJ, Fraser, E, Hubacek, K, Prell, C & Reed, MS 2006, 'Unpacking “participation” in the adaptive management of social–ecological systems: a critical review', *Ecology and society,* vol. 11, no. 2, p. 22.

Thomas, DR 2006, 'A general inductive approach for analyzing qualitative evaluation data', *American journal of evaluation,* vol. 27, no. 2, pp. 237-246.

Tress, B & Tress, G 2003, 'Scenario visualisation for participatory landscape planning—a study from Denmark', *Landscape and Urban Planning,* vol. 64, no. 3, pp. 161-178.

UNISDR 2015, *Sendai Framework for Disaster Risk Reduction 2015-2030*, UNISDR, Sendai, Japan.

UNISDR 2017, *Terminology*, viewed 27/07/17, https://www.unisdr.org/we/inform/terminology.

Van Eck, NJ & Waltman, L 2007, 'VOS: A new method for visualizing similarities between objects', in *Advances in data analysis*, Springer, pp. 299-306.

van Eck, NJ & Waltman, L 2010, 'Software survey: VOSviewer, a computer program for bibliometric mapping', *Scientometrics,* vol. 84, no. 2, pp. 523-538.

Van Tatenhove, JP & Leroy, P 2003, 'Environment and participation in a context of political modernisation', *Environmental values*, pp. 155-174.

Volkery, A & Ribeiro, T 2009, 'Scenario planning in public policy: Understanding use, impacts and the role of institutional context factors', *Technological Forecasting and Social Change,* vol. 76, no. 9, pp. 1198-1207.

von Wirth, T, Wissen Hayek, U, Kunze, A, Neuenschwander, N, Stauffacher, M & Scholz, RW 2014, 'Identifying urban transformation dynamics: Functional use of scenario techniques to integrate knowledge from science and practice', *Technological Forecasting and Social Change,* vol. 89, pp. 115-130.

Wallerstein, N 1999, 'Power between evaluator and community: research relationships within New Mexico's healthier communities', *Social Science & Medicine,* vol. 49, no. 1, pp. 39-53.

Waltman, L 2016, 'A review of the literature on citation impact indicators', *Journal of Informetrics,* vol. 10, no. 2, pp. 365-391.

Walz, A, Lardelli, C, Behrendt, H, Grêt-Regamey, A, Lundström, C, Kytzia, S & Bebi, P 2007, 'Participatory scenario analysis for integrated regional modelling', *Landscape and Urban Planning,* vol. 81, no. 1, pp. 114-131.

White, I & O'Hare, P 2014, 'From rhetoric to reality: which resilience, why resilience, and whose resilience in spatial planning?', *Environment and Planning C: Government and Policy,* vol. 32, no. 5, pp. 934-950.

Wondolleck, JM & Yaffee, SL 2000, *Making collaboration work: Lessons from innovation in natural resource managment*, Island Press.

World Bank 1998, *World development Report 1998/1999: Knowledge for Development*, New York: Oxford University Press, World Bank Publications.

Yang, K & Pandey, SK 2011, 'Further dissecting the black box of citizen participation: When does citizen involvement lead to good outcomes?', *Public Administration Review,* vol. 71, no. 6, pp. 880-892.

Zorn, C & Shamseldin, AY 2015, 'Post-disaster infrastructure restoration: A comparison of events for future planning', *International Journal of Disaster Risk Reduction,* vol. 13, pp. 158-166.

3. Transport infrastructure performance and management in the South Island of New Zealand, during the first 100 days following the 2016 M_w 7.8 “Kaikōura” earthquake

Alistair J. Davies[1], Vinod Sadashiva[2], Mohammad Aghababaei[3], Danielle Barnhill[1], Seosamh B. Costello[3], Briony Fanslow[1], Daniel Headifen[4], Matthew Hughes[1], Rudolph Kotze[4], Janelle Mackie[5], Prakash Ranjitkar[3], James Thompson[5], Daniel R. Troitino[4], Thomas Wilson[1], Stuart Woods[6], Liam M. Wotherspoon[3].

[1] University of Canterbury, Christchurch, New Zealand.

[2] GNS Science, Lower Hutt, New Zealand.

[3] University of Auckland, Auckland, New Zealand.

[4] KiwiRail, Wellington, New Zealand.

[5] Canterbury Civil Defence & Emergency Management, Christchurch, New Zealand.

[6] New Zealand Transport Agency, Christchurch, New Zealand.

Journal: Bulletin of the New Zealand Society for Earthquake Engineering

Submitted: March 2017

Reviewed: May 2017

Accepted: May 2017

Published: Vol. 50, No. 2, June 2017

3.1 Abstract

At 00:02 on 14th November 2016, a M_w 7.8 earthquake occurred in and offshore of the northeast of the South Island of New Zealand. Fault rupture, ground shaking, liquefaction, and co-seismic landslides caused severe damage to distributed infrastructure, and particularly transportation networks; large segments of the country’s main highway, State Highway 1 (SH1), and the Main North Line (MNL) railway line, were damaged between Picton and Christchurch. The damage caused direct local impacts, including isolation of communities, and wider regional impacts, including disruption of supply chains. Adaptive measures have ensured immediate continued regional transport of goods and people. Air and sea transport increased quickly, both for emergency response and to ensure routine transport of goods. Road diversions have also allowed critical connections to remain operable. This effective response to regional transport challenges allowed Civil Defence & Emergency Management to quickly prioritise access to isolated settlements, all of which had road access 23 days after the earthquake. However, 100 days after the earthquake, critical segments of SH1 and the MNL remain closed and their ongoing repairs are a serious national strategic, as well as local, concern.

This paper presents the impacts on South Island transport infrastructure, and subsequent management through the emergency response and early recovery phases, during the first 100 days following the initial earthquake, and highlights lessons for transportation system resilience.

3.2 Introduction

New Zealand is located on a tectonic plate boundary between the Australian and Pacific plates. The country exists because of this complex plate boundary; a subduction zone, along the east coast of the North Island, terminates northeast of the South Island, where it transitions into mostly strike-slip faults in the Marlborough and Alpine Fault regions (Figure 9).

At 00:02 on 14th November 2016, a M_w 7.8 earthquake occurred in the Marlborough area, resulting in two fatalities and 57 injured persons (Nicol et al., 2016). At least 21 faults ruptured on and offshore of the north-east of the South Island of New Zealand (Figure 10) (Stirling et al., 2017). The ruptures began on a fault near Culverden, approximately 15 km deep, and continued north-eastwards for more than 170 km, at a rupture speed of around 1.8 km/s (6,450 km/hr), with Peak Ground Accelerations of around 1.3 g (Hamling et al., 2017; Nicol et al., 2016). Initial estimates suggest between 80,000 and 100,000 landslides were triggered by the earthquake, within an area of 10,000 km^2, with most of the co-seismic landslides located within an area of 3,600 km^2 (Figure 10) (Nicol et al., 2016). Five landslides were more than 1,000,000 m^3 in size, and 50 large landslide dams were identified (Dellow et al., 2017; Nicol et al., 2016).

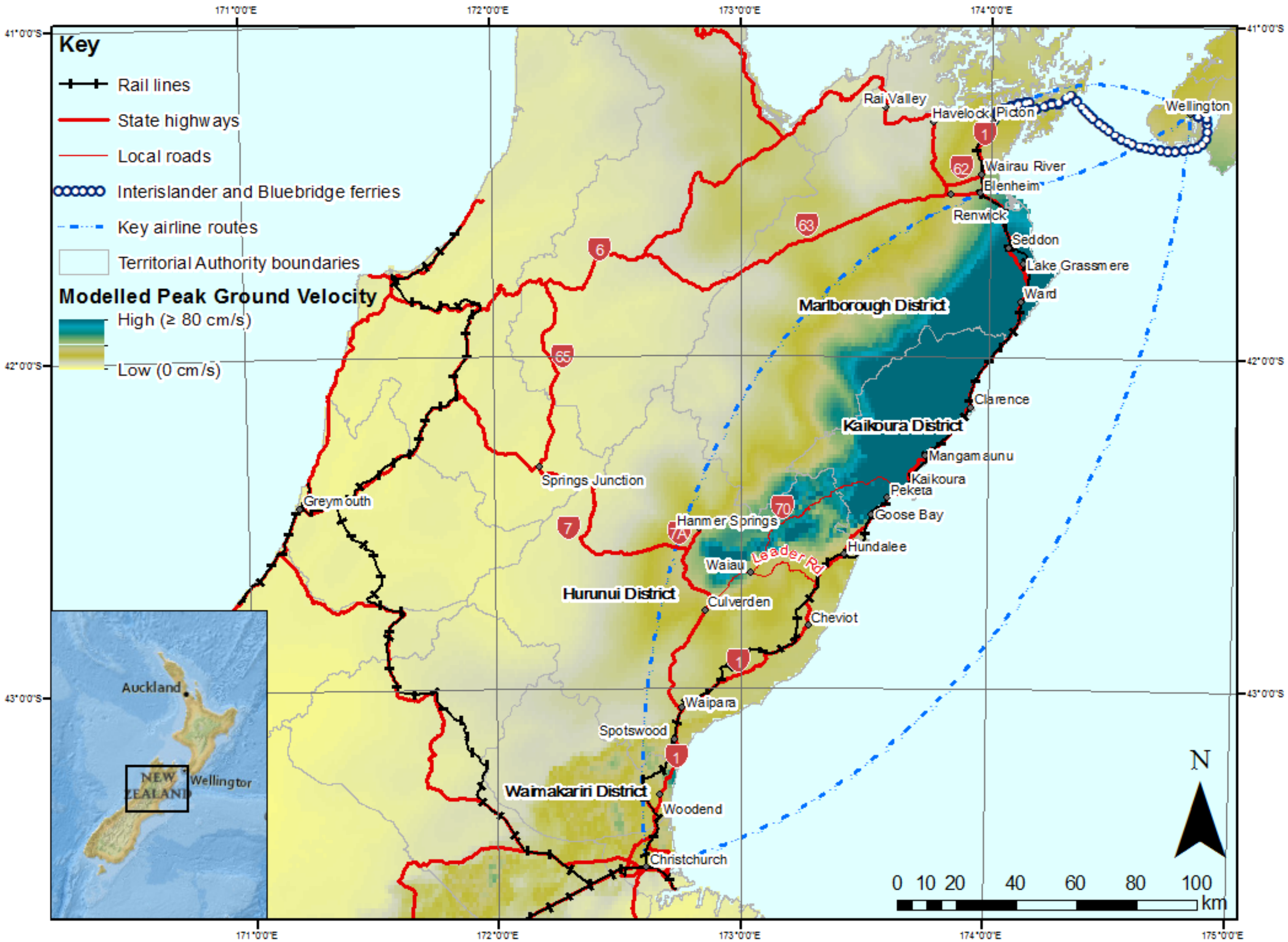

Figure 9. Modelled Peak Ground Velocity on land of the 14th November 2016 M_w7.8 “Kaikōura” earthquake (Bradley et al., 2017), with key transport networks overlaid, and New Zealand’s tectonic setting (inset).

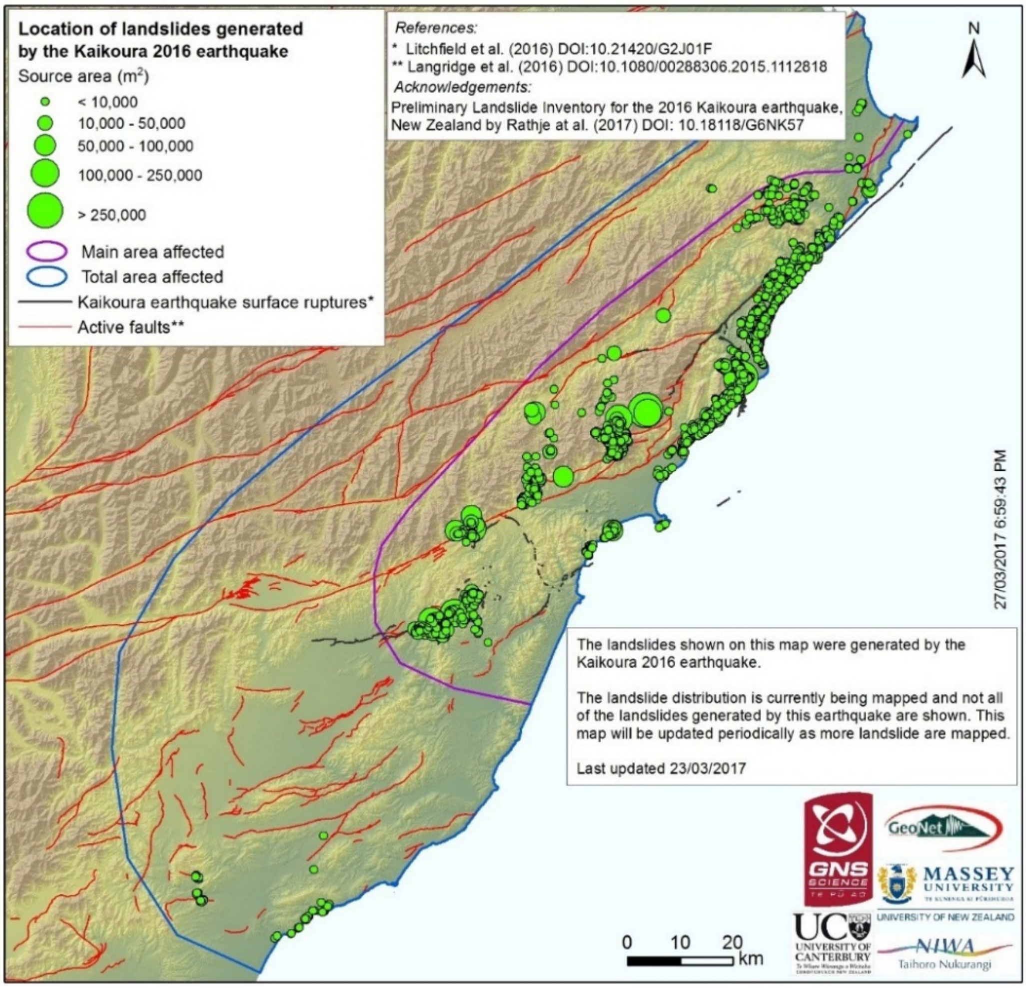

Figure 10. Preliminary Landslide Inventory for the 2016 Kaikōura earthquake, New Zealand by QuakeCoRE, GEER, and EERI (Bradley et al., 2017).

The earthquake caused widespread damage across the northeast of the South Island, including to Kaikōura, a popular tourist destination, and also damaged Wellington, the country’s capital (Bradley et al., 2017). Fault rupture, ground shaking, liquefaction, and co-seismic landslides also damaged distributed infrastructure across a wide region. In particular, transportation networks were severely affected, including a number of state highways in central and northern areas of the South Island, including State Highway 1 (SH1) in the Kaikōura District, and the Main North Line (MNL) railway line between Picton and Christchurch (Figure 9). See Stevenson et al. (2017) for a summary of the economic and social impacts.

SH1 is New Zealand’s main highway, and runs the length of the country, supplemented by a ferry crossing between the North and South islands, run by Interislander and Bluebridge ferries (Figure 9). Prior to the earthquake, SH1 provided the main link between Picton and Christchurch (341,500 residents; Stats NZ, 2013), and beyond to the remainder of the South Island (Figure 11). SH1 was by far the shortest road route between Picton and Christchurch at around 4 ½ hours, with the closest state highway alternative route taking around 6 ½ hours. Accordingly, SH1 carried substantial volumes of traffic and was a route for transport of goods, as well as being a popular tourist drive (Figure 11).

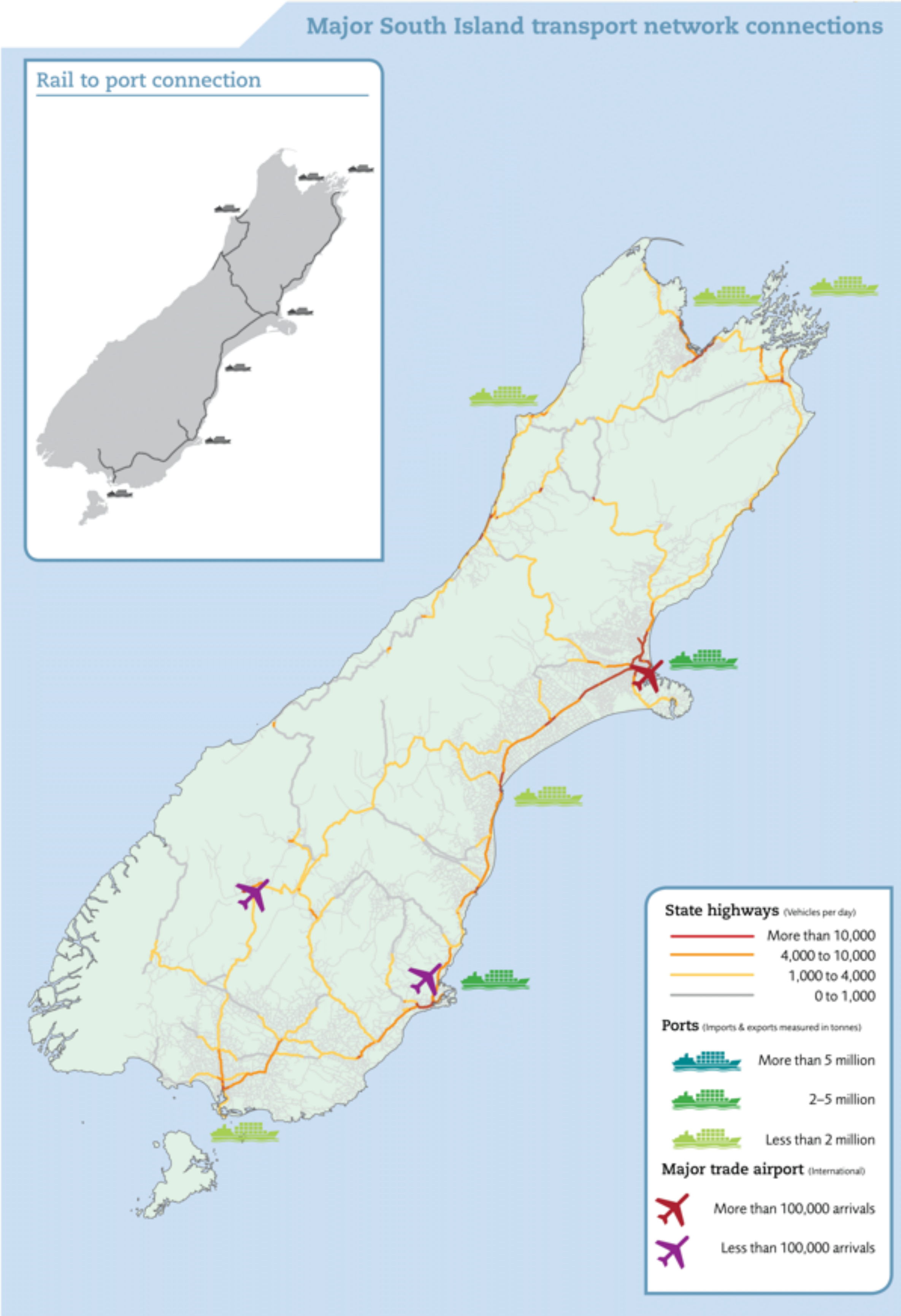

Figure 11. Major South Island transport usage by Ministry of Transport (2011) (note: there is no longer a Nelson port to rail connection).

The 350 km-long MNL runs alongside SH1 and is a critical network, moving about 1 million tonnes of freight between Picton and Christchurch annually (Kilroy, 2017) (Figure 11). The MNL is also a major tourist attraction, with the Coastal Pacific train (a KiwiRail Scenic journey service) providing a daily passenger service between Picton and Christchurch between the months of October and April.

The disruption of these transport networks caused a number of direct localised impacts, such as acute isolation of affected communities, including Kaikōura township and a number of rural farming communities, through to wider regional impacts such as disruption of supply chains (Market Economics, 2017).

This paper presents the impact of the 14th November 2016 M_w 7.8 earthquake on South Island transport infrastructure, and subsequent management through the emergency response and early-recovery phases, up until the 21st February 2017, 100 days after the initial event. Direct impacts on the transport network, a timeline of events, level-of-service maps, as well as secondary impacts are presented. Lessons learned from the event are also highlighted.

3.3 Natural hazard resilience planning responsibilities and initiatives for transportation networks in New Zealand

3.3.1 New Zealand infrastructure resilience

When considering the impacts of the Kaikōura earthquake on transport networks, it is important to consider the organisational arrangements and legislative context. New Zealand recognises that infrastructure ‘is the foundation on which so much of our economy relies’ (National Infrastructure Unit, 2015, p. 7), and so the Treasury formed a National Infrastructure Unit (NIU), which is advised by the National Infrastructure Advisory Board (which also advises the Minister of Finance and infrastructure providers). The NIU is responsible for ensuring New Zealand’s infrastructure is ‘resilient and coordinated and contributes to a strong economy and high living standards’ (National Infrastructure Unit, 2015, p. 4).

The NIU has progressed from initially planning short-term priorities for infrastructure investment and regulatory reform, when established in 2009, to producing the *Thirty Year New Zealand Infrastructure Plan 2015* (National Infrastructure Unit, 2015). Part of this plan aims to move New Zealand infrastructure planning away from being “asset-driven”, where assets are ‘designed and built without fully considering the service being delivered’ (National Infrastructure Unit, 2015, p. 46), to ensuring infrastructure providers understand end users’ needs. This priority was highlighted again in the Treasury’s *Progress one year on from the Thirty Year New Zealand Infrastructure Plan* report, which states ‘simply building things to address our problems is no longer sustainable. We need a better understanding of the levels of service we want to deliver, more mature asset management practices and use of data, and more effective decision-making that considers non-asset solutions’ (The Treasury, 2016, p. 5). Therefore, New Zealand government policy increasingly views infrastructure in terms of the integrated service provided; instead of, for example, considering roads, rail lines, shipping and air travel separately, increasingly the focus is on the ability to transport goods and people around the integrated transport network, regardless of the transport mode.

The Civil Defence & Emergency Management Act 2002 (MCDEM, 2002, Section 60, p. 40) requires lifeline utilities to be ‘able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency’. To this end, New Zealand has an increasingly strong “Lifelines” culture. Lifeline utilities are entities that provide essential infrastructure services to communities and have responsibilities for planning and coordinating in a way which enables the continuation of these services in an emergency, as part of Civil Defence & Emergency Management (CDEM) Groups, the Ministry of Civil Defence & Emergency Management (MCDEM), and other relevant government agencies and regulatory bodies, legislated under the *National Civil Defence Emergency Management Plan Order 2015* (DPMC, 2015). A key feature of the Lifelines culture in New Zealand are the 16 Regional Lifelines Groups across New Zealand, with national representation and coordination undertaken by the New Zealand Lifelines Council (est. 1999). These regional entities, made up of lifeline utility representatives, undertake collaborative work with scientists, engineers and emergency managers to identify interdependencies and vulnerabilities to regional scale emergencies. This collaborative process provides a framework to enable integration of asset management, risk management and emergency management across utilities (Fenwick, 2012; New Zealand Lifelines Committee, n.d.).

A notable success story of the value of the Lifelines concept is the Christchurch Engineering Lifelines’ *Risks and Realities* project (Lamb, 1997), which identified a number of vulnerabilities and interdependencies in Christchurch in the late 1990’s and over the subsequent decade implemented a suite of disaster risk reduction measures. A review of the impact of these mitigation measures following the 2010/2011 Christchurch earthquake sequence found ‘the damage would have been greater and the response slower if the steps recommended in *Risks and Realities* and other preparatory work fostered by the Group had not been taken. For example, Orion’s electricity distribution seismic strengthening programme, commenced in 1996 and progressed systematically each year, cost $6 million and is estimated to have saved $60 to $65 million in direct asset replacement costs and repairs’ (Fenwick, 2012, p. ii; Giovinazzi et al., 2011).

3.3.2 New Zealand transport network

The New Zealand transport network is owned and operated by several different organisations. The New Zealand Transport Agency (NZ Transport Agency) is an independent crown entity, responsible (amongst other roles) for allocating funds from the National Land Transport Funds to land transport activities, including local roads, state highways and public transport and, together with local and regional government, for funding local roads and public transport infrastructure and services. NZ Transport Agency is responsible for the state highway road network (Figure 9). Local roading is the responsibility of territorial authorities in the form of district or city councils. KiwiRail is a state-owned enterprise and the largest rail transport operator in New Zealand, including rail operations in the South

Island, and Interislander ferries (Figure 9). KiwiRail’s ‘core purpose’ is to move people and freight, and aims to add value to New Zealand transport by helping their customers to be more competitive, assisting with the Government’s Business Growth Agenda and offering world-class tourism experiences (KiwiRail, 2016). Bluebridge operates the other main ferry service between Picton and Wellington (the South and North islands) (Figure 9). Numerous other shipping companies operate throughout New Zealand waters, and numerous private airlines operate throughout the country (Figure 9, Figure 11). Air New Zealand is the national airline, 53% owned by the New Zealand Government.

NZ Transport Agency and KiwiRail (alongside Transpower, the national electricity provider) have developed a shared resilience response framework, aligned with the *Thirty Year New Zealand Infrastructure Plan 2015* (New Zealand Transport Agency, 2014). Using a consistent approach allows better management of, and cooperation between, the networks. Resilience is viewed by the collaborators as being concerned with any event, natural or man-made (including, for example, climate change), which could disrupt the networks. The framework is based around three strands: 1) prevention, mitigation and preparedness; 2) emergency response; and 3) restoration and rehabilitation.

NZ Transport Agency has undertaken further resilience work specific to its network, through: business continuity planning; identifying alternative routes to state highway links; creating a system to advise customers of events, impacts and their options; and continuing with seismic retrofit, bridge scour and rockfall mitigation programmes; avalanche and weather monitoring programmes; efforts to proactively reduce ice formation on road surfaces; and to build new structures to modern standards (New Zealand Transport Agency, 2014). However, NZ Transport Agency’s most recent *State Highway Network Resilience National Programme Business Case* (New Zealand Transport Agency, 2014, p. 3) identified a number of areas where improvements were needed:

- ‘while alternative routes are planned for each state highway these are not consistently recorded, nor do they all have sufficient capacity to be viable alternatives without upgrade;
- ‘there is an inconsistent process used in different regions for assessing natural risks making it difficult to consistently assess, compare and prioritise service gaps and potential responses;
- ‘there has been no systematic framework for recording events, or assessing infrequent risks so current knowledge of risk tends to be dominated by the frequently occurring events causing a dearth of reliable systematic assessment of the scope, location or risk of infrequent events’.

NZ Transport Agency’s Capital Works Programme develops projects based upon a range of criteria, including a cost-benefit analysis, which can make it difficult to deliver projects with “resilience” as the primary objective or justification, though it should be noted “resilience” is often a secondary objective in Capital Works Programme projects. This is because, for example, even for a relatively frequent natural hazard recurrence interval of 50 years, the annual benefit needs to be divided by 50. Calculating a Net Present Value (calculated for a 40-year period and with a relatively low 6% discount rate) from the annualised benefit stream often results in a value so small that it rarely becomes a priority, compared to other possible improvements such as road safety.

KiwiRail have developed several systems for consistent nationwide review of resilience related issues. Rating individual slopes in terms of a “Slope Risk Ranking” allows individual slopes to be compared on a consistent basis across the national rail network. Over 3,000 slopes have been ranked in this manner. Additionally, KiwiRail records all incidents across the rail network and regularly reviews these compared to asset information such as the Slope Risk Ranking. From this investment, choices for mitigation can be undertaken.

Network-specific resilience improvements have also been made for shipping and air transport, as lifeline utilities. Unfortunately, there is little publicly-available relevant information on specific initiatives for these networks.

Isolated settlements, as well as wider regions supported by supply chains, are increasingly dependent upon distributed infrastructure. Due to this dependency, by causing damage to distributed infrastructure, natural hazards can now threaten beyond their local, direct impacts. The 14th November 2016 earthquake offers important insights into these increasing risks, and, accordingly, the success of specific resilience initiatives within the transport sector.

3.4 Method

This paper presents the impact of the 14th November 2016 M_w 7.8 earthquake on South Island transport infrastructure, and subsequent management through the emergency response and recovery phases, up until 21st February 2017, 100 days after the initial earthquake. Throughout this paper, dates are referred to as “Day X”, with 14th November 2016 being Day 1 and 21st February 2017 Day 100. This paper uses data immediately available after the emergency response phase. A complete overview of the physical and functional performance of all South Island transport is beyond the scope of this paper.

The earthquake and co-seismic hazards, as well as direct impacts on road, rail, bridges, shipping and air transport are briefly summarised before presenting a detailed timeline of key transport events, derived from discussions with representatives from the NZ Transport Agency Christchurch branch, Canterbury CDEM, and KiwiRail (co-authors), as well as publicly-available information from NZ Transport Agency, KiwiRail, CentrePort, SoundsAir, CDEM, Marlborough District Council, Kaikōura District Council, Hurunui District Council, Waimakariri District Council, and the media. From this timeline, maps are produced to show level-of-service changes between 14th November 2016 (Day 1) and 21st February 2017 (Day 100), for: state highway roads and alternative routes; rail lines, Interislander rail-enabled ferry services and official KiwiRail diversions; Interislander and Bluebridge vehicle and passenger ferries; and commercial flights between Kaikōura, Christchurch, Wellington, Blenheim, and Picton. Secondary impacts are then presented, before discussing the timeline of transport interdependencies during the emergency response and initial days of recovery in the South Island, followed by lessons from the event.

3.5 Impact assessment

3.5.1 Direct impacts

The direct impacts of the earthquake and co-seismic hazards on road, rail, bridges, air transport and shipping are summarised below.

3.5.1.1 Road

The impact of the earthquake on roading was severe. Prior to the earthquake, the travel time between Christchurch and Picton was around 4 ½ hours using SH1. Immediately after the earthquake, the road travel time increased to more than 8 hours. SH1, New Zealand’s main highway, was closed between Waipara and Wairau River township and SH7 (including SH7A) was closed between Waipara and Springs Junction (Figure 20). Smaller roads (including Route 70) were also closed, making Kaikōura, Hanmer, and a number of smaller settlements in the area inaccessible by land. Freight, vehicle and passenger ferry services between the North and South islands were suspended until damage to Wellington port could be assessed and berths cleared for use (Figure 20).

Ground movements caused severe road cracking due to slope failure beneath the carriageway (Figure 13a) and vertical and horizontal displacement due to fault rupture (Figure 13b), making the roading network impassable at a number of locations immediately after the event (Stirling et al., 2017, provides an overview of fault rupture locations and impacts). Road damage due to slope instability beneath the carriageway was repaired in the first few days following the earthquake in all locations apart from those inaccessible due to other damage typologies. The earthquakes also increased the risk of co-seismic hazards. Co-seismic landslides (Figure 13c) and rockfalls (Figure 13d) closed the road in a number of places, and have presented one of the greatest challenges in repairing the road requiring a substantial amount of time and effort to clear. A more complete summary of landslides and their impacts is presented in Dellow et al. (2017).

By the end of Day 1, SH1 had reopened from Waipara to Cheviot and SH7 between Waipara and Springs Junction (including daytime access along SH7A to Hanmer Springs, which was no longer isolated) (Figure 21), resulting in the travel time between Christchurch and Picton reducing to around 6 ½ hours. By Day 2, car ferry services had also resumed, albeit reduced services, making road travel between the North and South islands viable again (Figure 22).

CDEM quickly prioritised access to isolated settlements, in particular to provide essential supplies including water, food and fuel, and to evacuate the hundreds of tourists who were trapped in Kaikōura (primarily to reduce the load on local supplies). Prior to the earthquake, Kaikōura was accessible from the north and south by a coastal rail service and SH1, as well as via Route 70 from the south-west (Figure 9). Most of the smaller settlements in the area were accessible exclusively by road. Following the earthquake, settlements (including Kaikōura) were inaccessible by land (Figure 21).

Despite facilitating efficient evacuation, access via air and sea were both unreliable. For air access, poor weather conditions could (and did) result in no-fly days, and for sea access, damage to Kaikōura port, as well as its small size, meant few vessels could dock (Cropp, 2016). The sea bed around the port was uplifted and so needed to be re-surveyed for access for anything other than small boats (Stirling et al., 2017). This meant access was dependent on the ability to moor offshore, and thus sea conditions. Therefore, it became critical to re-establish road access.

NZ Transport Agency began to clear SH1 from the south of Kaikōura at 06:00 on Day 2, a decision NZ Transport Agency described as “fairly self-evident” because the landslides north of Kaikōura were much larger, meaning there was greater opportunity to pursue getting the roads open to the south. While work began on clearing SH1, a number of options were considered by NZ Transport Agency and CDEM, and Route 70 was decided as the most feasible road to secure quick access to Kaikōura.

Within the first few days, SH1 between Peketa and Mangamaunu was opened (Figure 23), and army convoys began travelling along Route 70 through to Kaikōura (and so also reached Peketa and Mangamaunu). These convoys carried essential supplies, at the request of the Emergency Operation Centre in Kaikōura and Canterbury CDEM. Before the convoy proceeded, a 10-step “Go/No Go” assessment (Figure 12) was conducted every morning at around 06:00, which involved a visual assessment of the road and geohazards (including landslide reconnaissance) by helicopter, or by road if the weather did not permit flying, weather forecast assessment, establishing whether the travel was essential, and creation of a recovery plan. Later, specific vehicles needed to repair critical infrastructure were also permitted access along Route 70.

Go / No Go

Weather + Fx	
Road State	
Geo Tech Risks	
Other Road Users/Activities	
Emergency Response Procedure in Place	
Turn Back Criteria	
Public Messaging	
‘Safe’ Zones Identified	
‘High Hazard’ Zones	
Load, Speed, Weight Restrictions	

Date: ________________ **Time:** _______

Signed ____________________________

Saved on CDEM dutyofficer Desktop   File Name: Go No Go

Figure 12. Canterbury CDEM “Go/No Go” criteria.

a) Pavement cracking on SH1 due to slope instability. Photo credit: Dizhur & Giaretton.

b) Pavement rupture due to fault rupture and subsequent access ramp. Photo credit: Dizhur & Giaretton.

c) Landslide on SH1, north of Kaikōura. Photo credit: Tonkin & Taylor.

d) Rockfall on SH1, north of Kaikōura. Photo credit: Dizhur & Giaretton.

Figure 13. Photos of road damage on SH1, following the 14th November 2016 earthquake.

a) Rail line suspended by fault rupture (angle 1). Photo credit: Dizhur & Giaretton.

b) Rail line suspended by fault rupture (angle 2). Photo credit: Dizhur & Giaretton.

c) Large offset of rail track due to landslide. Photo credit: Dizhur & Giaretton.

d) Large offset of rail track due to landslide. Photo credit: William Ries, GNS Science.

e) Rail tracks severely distorted and misaligned due to fault rupture. Photo credit: William Ries, GNS Science.

f) Cracking of tunnel wall. Photo credit: KiwiRail.

Figure 14. Photos of rail damage, following the 14th November 2016 earthquake.

Road access was a balancing act between three factors: 1. repair of the road; 2. (emergency) supplies for Kaikōura; and 3. access for residents (particularly for farmers to make repairs). Prioritisation of any of the factors slowed down the other two, meaning effective management and operation was critical.

By Day 4, SH1 was open between Blenheim and Ward, and there was controlled access along SH1 between Cheviot and Goose Bay, reducing the number of completely isolated settlements (Figure 24).

On Day 11, the first non-emergency vehicles travelled out from Kaikōura. 81 vehicles travelled in convoy, subdivided into vehicle classes (i.e. cars, trucks), through Route 70 under heavy supervision due to the risk the road still presented. Those wishing to travel in a convoy registered beforehand, and met in specified locations before proceeding, subject to the “Go/No Go” criteria. Daily convoys in and out of Kaikōura along Route 70 continued until Route 70 was switched to controlled access for residents and emergency services on Day 23, when SH1 between Ward and Clarence was also opened for controlled access, meaning all settlements had road access (Figure 29). However, the SH1 diversion remains in place 100 days after the event, as SH1 remains closed between Mangamaunu and Clarence as repair works continue (Figure 32).

On Day 38, Route 70 was fully reopened and daytime access between Goose Bay and Peketa along SH1 to Kaikōura was also permitted, adding some redundancy in accessing Kaikōura (Figure 31). This section of SH1 closed three times during December and January, twice for a few hours due to weather conditions increasing the risk of rockfall onto the highway, and then for two days due to a slip. Route 70 remained open throughout.

3.5.1.2 Rail

The earthquake and co-seismic hazards caused substantial damage to the rail network. Immediately following the earthquake, all rail and rail ferry services between Palmerston North (north of Wellington) and Christchurch were suspended by KiwiRail until a rapid survey of the affected region was completed (Figure 33). One train was trapped between damaged sections of the Main North Line (MNL) north of Kaikōura, as it stopped where it was during the earthquake (as is normal operating procedure). The train was not damaged by the earthquake.

While passenger rail services in the Wellington area fully resumed within 3 days following the earthquake, the majority of the MNL remains closed over 100 days later (Figure 38).

KiwiRail started to assess and inspect the damage immediately after the earthquake, following the procedure in their “Earthquake Response for Infrastructure” Standard, with track gangs and inspectors undertaking visual inspections on accessible areas and flyovers over the inaccessible section around Kaikōura. Engineering inspections also commenced within two days of the earthquake, with multiple teams assessing damage simultaneously along the MNL. In order to maintain consistency in recording damage observations made by the multiple teams, a KiwiRail-developed “Damage Classification Guideline” for rail assets was used. Continued aftershocks and the very high risk of further landslides meant inspections had to be conducted in a controlled fashion.

The impact of aftershocks was assessed according to the above KiwiRail Standard, which required constant review of Peak Ground Acceleration (PGA) readings following aftershocks and subsequent inspections (when required).

Preliminary observations suggest that about 700-750 sites along the MNL were affected by this event, with tracks, bridges, tunnels, culverts, slopes, embankments and communication systems all damaged to varying degrees (Radio New Zealand, 2017). Figure 14 and Figure 15 show examples of damage observed and recorded from the visual inspections. Detailed damage observations on rail assets are still being collated.

Rapid assessment and repairs were made to reopen the MNL between Picton and Blenheim by Day 3, thus providing rail access to carry freight from Picton to the container transfer site at Springs Creek, north of Blenheim (to be later delivered by truck to Christchurch) (Figure 34).

The rail service between the North and South islands also relies upon a rail-enabled ferry. This did not resume sailing until Day 16, when the link span at the CentrePort ferry terminal in Wellington, used to load and discharge vehicles, was repaired (Figure 35).

Repair works on the heavily damaged MNL continued throughout the Christmas holiday period. This resulted in the reopening of a significant section of the MNL between Picton and Grassmere by Day 64, which allowed commercial goods to be carried between Dominion Saltworks at Lake Grassmere and Picton (Figure 37). These repairs also freed train wagons trapped near Lake Grassmere, allowing the carriages to be re-distributed around the rail network. The train stopped partially within a tunnel near Kaikōura, has been moved to a different location along the MNL to take the heavy locomotives off a bridge to prevent damage from future aftershocks, but remains trapped. Work trains were able to be run from Christchurch north to Bridge 83 on the MNL for load testing of the structures on Day 25, but could not travel further due to formation and bridge damage.

Numerous teams continue to work collectively to identify badly damaged assets and to explore repair strategies, with achievements including: completed concept designs for strengthening and/or replacements of major damaged bridges and initial construction schedules; continued repairs to twisted tracks; detailed geotechnical assessments and testing carried out at a number of affected sites to prepare for major earthworks; and surveying of damaged tunnels to determine repair work required. Three months following the earthquake, repair and restoration works on 120 out of over 800 sites have been completed, and efforts are continuing to restore the remaining sections of MNL back to full service by the end of 2017.

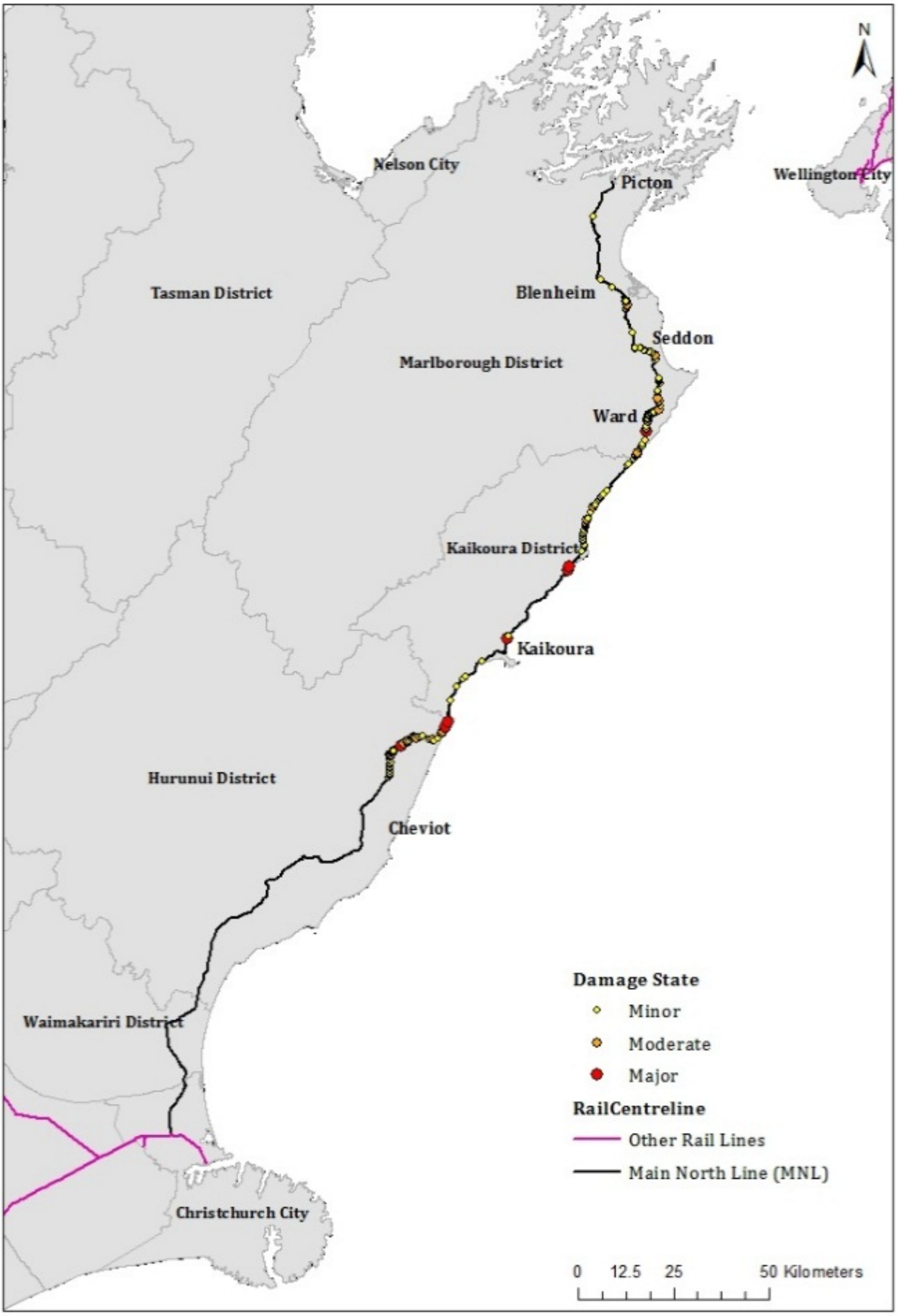

Figure 15. Track damage states assigned (following the “KiwiRail Earthquake Damage Classification Guideline”) based on visual inspection of tracks: Minor (e.g. very minimal damage to rail and/or sleepers), Moderate (e.g. subsidence of track >150mm and/or over a distance >50m), and Major (e.g. significant vertical and/or horizontal movement).

3.5.1.3 Bridges

The vast majority of bridges performed well during the earthquake, with most being allowed to re-open after inspection in the first few days after the earthquake. Some bridges with damage to their piers were cleared for use before repairs were completed (Figure 16b, Figure 16c, Figure 16d).

Although the bridge structures withstood the earthquakes well, demonstrating considerable robustness, many bridge approaches were damaged due to settlement and horizontal movement (Figure 16a), thereby making some bridges impassable. Approach reconstruction through the placement of fill and resealing quickly made the majority of these road bridges usable again. In some locations diversions were put in place to bypass damaged road bridges (such as the Oara Bridge in Figure 16a that crosses rail lines), and along Route 70 one bridge was replaced by a temporary Bailey bridge alongside the repair to other parts of the Route to allow for access. Displacement is a greater problem for rail lines than roads, whether vertical or horizontal (Figure 16e). However, given the damage to other parts of the rail network, this damage is not immediately critical, and repair can be scheduled accordingly.

Palermo et al. (2017) provide an in-depth summary of the structural and geotechnical engineering-related impacts to road bridges.

3.5.1.4 Shipping

Most ports throughout New Zealand were undamaged by the earthquakes, with the major exception of CentrePort in Wellington, which suffered substantial damage due to liquefaction-induced settlement and lateral spreading, rendering the port’s container cranes inoperable (Cubrinovski et al., 2017).

Two ferry services, Bluebridge and Interislander, provide the main ferry link between the North and South islands between Wellington and Picton. Ferry services between Wellington and Picton resumed by Day 2 (Figure 22), with the only major restriction being for foot passengers, who could not board the ferries due to terminal damage. By Day 4, foot passage was again possible both ways between Wellington and Picton on Bluebridge services (Figure 24), although full Interislander operation did not resume until Day 23 (Figure 29).

Kaikōura port was also damaged. The sea bed around the port was uplifted and needed to be re-surveyed for access for anything other than small boats (Stirling et al., 2017). In part also due to its small size, this meant sea access to Kaikōura was dependent on the ability to moor offshore, and thus sea conditions.

3.5.1.5 Air Transport

There were no major direct impacts to the air network. Wellington and Christchurch international airports, and Kaikōura and Blenheim regional airports, were undamaged and virtually uninterrupted following brief (less than one hour) closures for inspections.

a) Oaro bridge approach failure and pavement cracking. Photo credit: Dizhur & Giaretton.

b) Lower Mason bridge with damaged supports. Photo credit: Dizhur & Giaretton.

c) Lower Mason bridge support damage. Photo credit: Dizhur & Giaretton.

d) Lower Mason bridge support repair. Photo credit: Liam Wotherspoon, UoA.

e) Rail bridge 97 MNL approach offset and rail alignment failure. Photo credit: Dizhur & Giaretton.

f) Rail bridge 129 MNL span dislocated from abutment due to Kekerengu Fault rupture. Photo credit: Tim Little, VUW.

Figure 16. Photos of bridge damage on SH1 and rail, following the 14th November 2016 earthquake.

3.5.2 Secondary impacts

3.5.2.1 Road

a) Ruptured ground with increased landslide risk to the road. Photo credit: Aurecon, 2016.

b) Landslide undercutting road, slumping potential. Photo credit: Aurecon, 2016.

Figure 17. Co-seismic impacts.

The vulnerability of the state highway network to different and cascading hazards presented a substantial risk throughout the emergency operation, and continues to do so during the recovery phase, especially to working crews who must carefully execute tasks in a controlled manner due to the risks. Figure 17a shows an example of fault rupture increasing the risk of a landslide onto the road, and Figure 17b shows an example where a landslide below the road has increased the risk of slumping. Canterbury CDEM noted these hazards were not apparent when viewed from road level, despite the obvious threat they presented when viewed from above as part of an aerial geotechnical assessment.

Perhaps the most substantial secondary impact to the state highway network was that the section of SH6 between SH63 and SH65 became the only section of road connecting Canterbury, the West Coast, Southland and Otago to the North Island through Picton and Wellington. Presently, there is no redundancy for this stretch of road, a problem which has been highlighted by the relative ease by which other state highways have been closed due to weather and fire events. These include SH6, which was partially closed between south of Havelock and north of Rai Valley township on Day 2 due to a slip and flooding following heavy rain, and more recently SH7, which was closed for over eight hours due to rural fire on 1st March 2017. Similar challenges exist for a road closure due to a vehicle crash, which becomes more likely with increased traffic flows.

In an attempt to reduce the risk of motor vehicle crashes on SH63, SH6, SH65 and SH7, NZ Transport Agency has increased signage, increased public communication with key messages, installed temporary traffic signals at one bridge, improved delineation, and reduced the speed limit from 100 km/h to 80 km/h, and down to 60 km/h through Wairau River township (Eder, 2016). Police enforcement has also increased, and NZ Transport Agency has also enhanced its response measures.

The additional traffic, particularly heavy truck freight, is causing further travel time delays, as well as accelerated pavement damage resulting in large additional maintenance costs. To increase road capacity, NZ Transport Agency has increased the number of passing bays to increase the number of overtaking opportunities, widened the sealed width of roads, and on SH63, constructed three new Bailey bridges alongside pre-existing one lane bridges, to allow simultaneous two-way traffic flow (Bartlett, 2017; Buick, 2017). Strengthening of large stretches of the alternative route’s pavement was also required, principally on SH63, as it was not originally designed for the traffic loading (diverted from SH1 and as well as diverted rail freight) now travelling the route.

3.5.2.2 Rail

The earthquake cost KiwiRail $12 million from loss of trade to the end of December, and KiwiRail estimates direct costs from loss of trade due to the disruption of the MNL will be around $25 million by the end of June 2017. Estimates suggest the total cost to repair the rail line will be approximately $500 million (25% of the total estimated $2 billion to restore the transport corridor), although 60-80% of this cost is likely to be met by KiwiRail insurance (Radio New Zealand, 2017).

The loss of the rail line caused increased use of the road and shipping networks (Figure 35); since the MNL is an important freight line, KiwiRail’s immediate efforts were focussed on minimising the disruption to the New Zealand exporters. This included trucking stock along the alternative state highway route and arranging rail alternatives for Wellington port freight customers to other North Island ports (Figure 35).

To further reduce disruption to freight customers, and to reduce truck congestion on already increased road demands, KiwiRail entered the coastal freight shipping market with a new “NZ Connect” service on Day 15 (with support of Ports of Auckland, Lyttelton Port of Christchurch and ANL Shipping) (Figure 35). Auckland and Christchurch ports expanded operations and rail services were increased from the ports’ inland hubs to maximise the effectiveness of the freight route.

The train trapped near Kaikōura (Section 3.5.1.2) was looted (Eder, 2017). This led to KiwiRail working with the police to better secure the remaining train cargo. On Day 38, a crane arrived to remove containers off the train, so they could be delivered by road.

Unrelated to the earthquake, a large rural fire closed the Christchurch to Greymouth line on 4th February 2017 (Day 83) (Figure 38), and this did not reopen until 22nd March, further reducing rail capacity within the South Island in the interim.

3.5.2.3 North Canterbury Transport Infrastructure Rebuild (NCTIR) alliance

Following the initial earthquake damage, there was multi-agency discussion about whether SH1 and the MNL railway line should be reopened, especially around the most severely damaged section between Mangamaunu and Clarence (Figure 32) (Davies et al., 2016; O'Connell, 2016). NZ Transport Agency report that within one to two weeks (following the earthquake), the question of whether to abandon the coastal road and instead develop an alternate route, such as upgrading the Molesworth Track or Rainbow Road, was raised. Both are poor quality, summer-only, roads that already exist. KiwiRail also report discussing possible alternatives but suggest these were less attractive and realistic than the road alternatives. During these discussions, it quickly became clear that reopening the existing coastal route was the most viable option, for three primary reasons:

1. Distance: the existing coastal route is by far the shortest route.
2. Cost: The existing coastal route would be able to be cleared many times over for the cost of upgrading other routes (which themselves are located in a high hazard risk area).
3. Reliability: regular winter closures versus occasional storm surge closures. Alternatives including the Molesworth Track and Rainbow Road traverse high mountain passes, and so would be closed many times during each winter just with snow and ice events. NZ Transport Agency considers infrequent (even when slightly more damaging) closures preferable to frequent closures.

Accordingly, the Government passed emergency legislation to ensure repairs to the coastal route could be accelerated, and on Day 32, Cabinet (a council of senior Government ministers which formulates Government policy) agreed to fund the works required, which were estimated at a cost of between $1.4 billion and $2 billion (Bridges, 2016b). Following this decision, on Day 38, the Government announced the North Canterbury Transport Infrastructure Rebuild (NCTIR) alliance, between NZ Transport Agency, KiwiRail, Fulton Hogan, Downer, Higgins and HEB Construction (Bridges, 2016a).

The alliance is responsible for SH1, Route 70, the SH7, SH65, SH6 and SH63 alternative route, and the MNL rail corridor. NCTIR is led by Duncan Gibb, former lead of the Stronger Christchurch Infrastructure Rebuild Team (SCIRT), and was formed to reduce delays caused by tendering for work, and to pool resources to ensure a more cost-effective repair of the rail and road, in the same approach used by SCIRT (Bridges, 2016a): this ability to pool resources was a key consideration when considering whether to repair the coastal route or upgrade an alternative.

NCTIR is operating as the lead delivery agency, managing, operating and undertaking all repair, recovery, rebuild and resilience works: where appropriate, NCTIR will take the opportunity to make some strategic resilience investments, such as road shoulder and lane widening, raising the road and/or tracks in areas susceptible to storm surges, and building rockfall and landslide mitigation structures, as can be found elsewhere in New Zealand (Figure 18). The extent to which such resilience measures are implemented is expected to be decided by mid-2017.

Figure 18. Otira rock fall shelter and aqueduct (Mattinbgn, 2011).

3.5.2.4 Shipping

Most ports throughout New Zealand were undamaged by the earthquakes, with the major exception of Centreport, Wellington, which suffered substantial damage. Many cargo ships were diverted from Wellington to other ports including Napier, Tauranga and Auckland. This contributed to a doubling of freight demand between Auckland and Christchurch, New Zealand’s busiest domestic sea route. A reduction in rail freight capacity also contributed to this increase in demand (Section 3.5.2.2).

Ferry services between Wellington and Picton resumed by Day 2 (Figure 22), with the only major restriction being for foot passengers, who could not board the ferries due to terminal damage. By Day 4, foot passage was again possible both ways between Wellington and Picton on Bluebridge services (Figure 24), although full Interislander operation did not resume until Day 23 (Figure 29).

Shipping was also used as a key emergency resource for Kaikōura, being used to evacuate 635 people from Kaikōura on HMNZS Canterbury to Lyttleton Port and provide emergency supplies for the township.

3.5.2.5 Air

Immediately following the earthquake, many settlements (including Kaikōura) were inaccessible by land. Therefore, helicopters were extensively used to access these settlements (there was huge demand for helicopter access from CDEM, infrastructure providers, media, scientists and other groups), as well as plane and sea access for Kaikōura, via its small airfield and port. Due to high usage, a five-day Temporary Restricted Area was established around Kaikōura on Day 4, to facilitate safe aircraft operation during the emergency response (Figure 19).

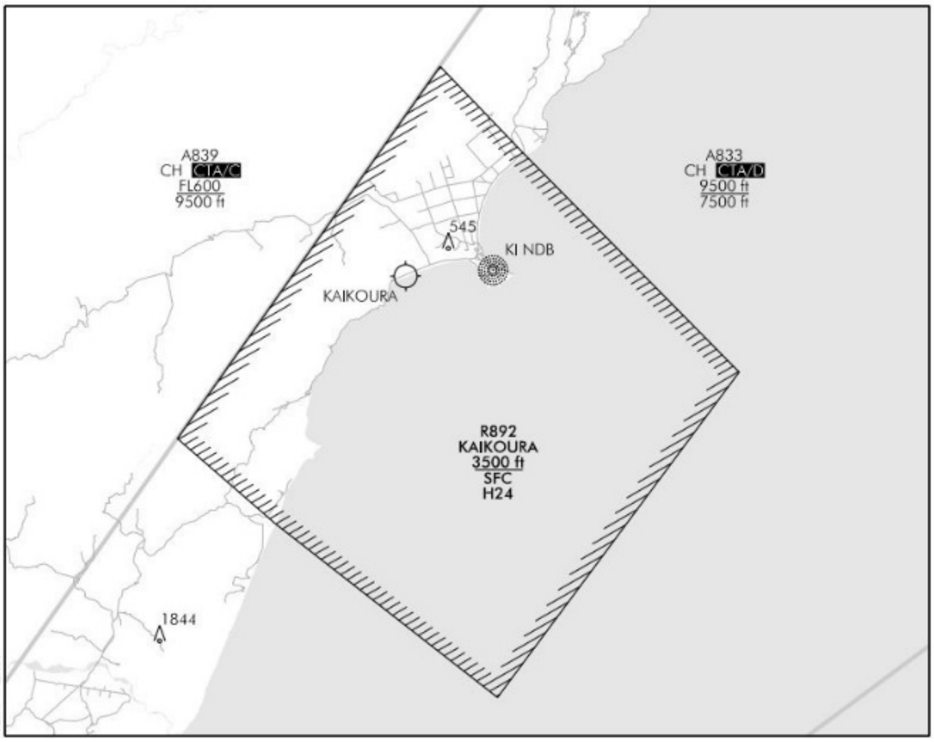

Figure 19. The five-day Temporary Restricted Area (NZR892) established in the Kaikōura Area on Day 4 (Jenkins, 2016).

To evacuate tourists (and vulnerable residents) quickly, a “don’t come back empty” policy was implemented by CDEM where possible and appropriate. The Emergency Operations Centre in Kaikōura prioritised evacuees, and through this policy, New Zealand Defence Force (NZDF) helicopters delivering emergency supplies to Kaikōura evacuated 198 people by the end of Day 2, and a further 165 by the end of Day 3. Air evacuees were received at Woodend by Waimakariri District Council and a number of agencies, including travel agents, on behalf of Canterbury CDEM.

Private airlines also added flights, providing capacity when other transport modes could not. On Day 2, Air New Zealand operated an additional return flight between Wellington and Marlborough, as ferries were reduced, and, with no road access, SoundsAir operated four flights from Kaikōura to Christchurch and Pelorus Air provided a charter service between Marlborough and Kaikōura (Figure 22). On Day 3, SoundsAir flew four flights from Kaikōura to Wellington (Figure 23). Additionally, on Day 8 (still with no public road access to Kaikōura), SoundsAir launched two temporary daily services, between Kaikōura and Christchurch and Kaikōura and Blenheim (Figure 26). As part of this service, the company also offered to carry the town’s postal deliveries on the flights (Lewis, 2016a). All these Kaikōura flights were new routes, and were limited to small aircraft, typically carrying 10 passengers, due to the length of the runway. Finally, SoundsAir added additional flights between Christchurch and Blenheim for the Christmas and New Year period, as demand increased due to the long inland road diversion (Figure 29) (Lewis, 2016b).

3.5.3 Timeline of key transport events

A detailed table of key transport events during the first 100 days following the 14th November 2016 is provided in Appendix C (Table 13).

The below maps show level-of-service changes between 14th November 2016 (Day 1) to 21st February 2017 (Day 100), for: state highway roads and alternative routes; rail lines and official KiwiRail diversions; Bluebridge and Interislander vehicle and people ferries; and commercial flights between Kaikōura, Christchurch, Wellington, Blenheim, and Picton. Where days are stated without times, the maps show level-of-service at the end of the day.

The maps are split into two sets. Figure 20 to Figure 32 show state highways and alternative routes, commercial flights and both Bluebridge and Interislander vehicle and passenger ferry services, which provide the main ferry link between the North and South islands between Wellington and Picton. Rail lines and official KiwiRail diversions are displayed separately in Figure 33 to Figure 38. This is largely because the rail and road network follow similar routes, making it difficult to display them on the same maps. The rail levels-of-service shown are for freight trains only; the daily rail passenger service between Picton and Christchurch has been cancelled until the end of 2017. The rail maps also show the level-of-service for the rail component of the rail-enabled Aratere Interislander ferry (the Aratere also carries vehicles and foot passengers, included in the vehicle and passenger ferry services: Figure 20 to Figure 32).

3.5.3.1 Level-of-service mapping for state highway roads and alternative routes, commercial flights, and Bluebridge and Interislander vehicle and passenger ferries.

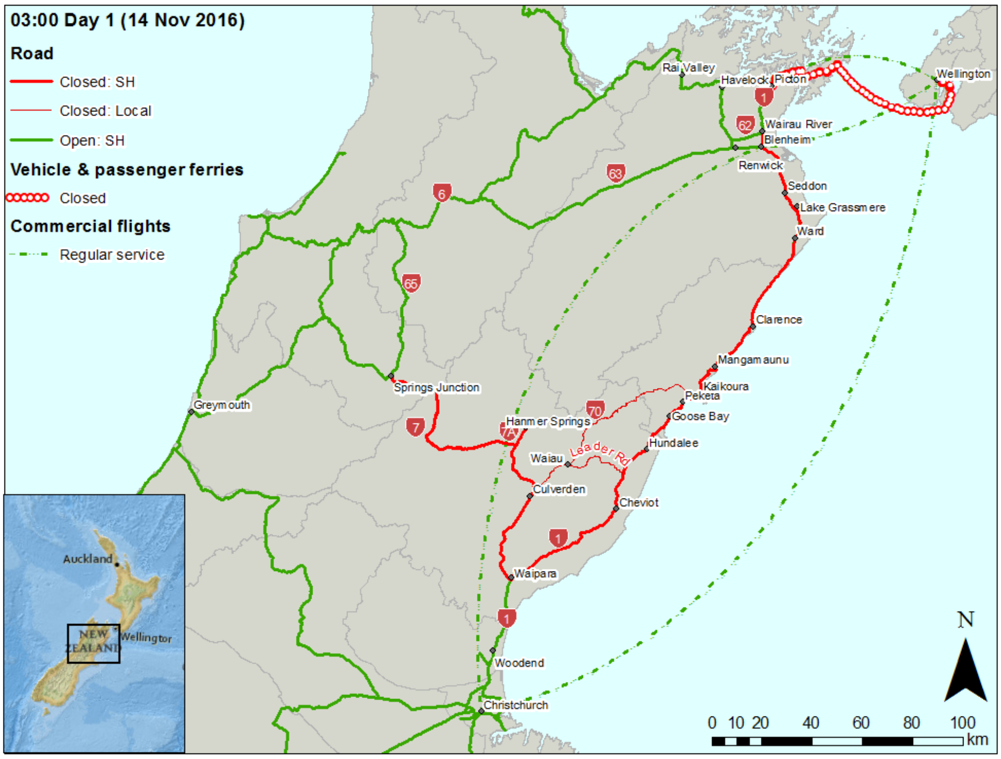

Figure 20. Level-of-service at 03:00 on Day 1 (14th November 2016).

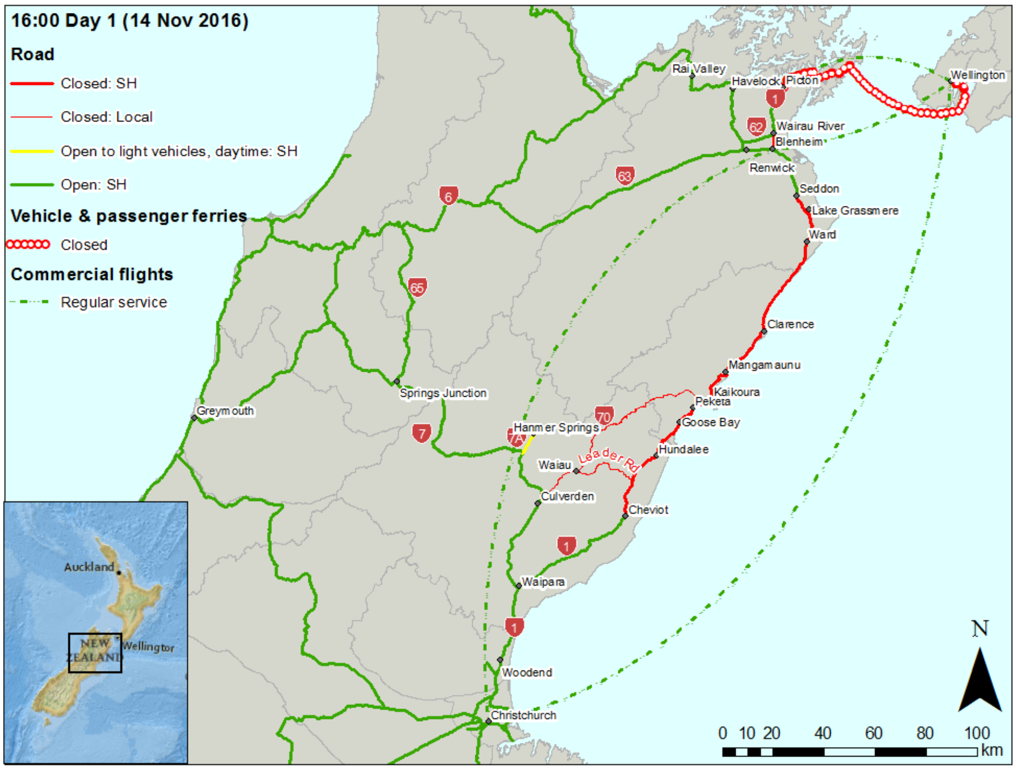

Figure 21. Level-of-service at 16:00 on Day 1 (14th November 2016).

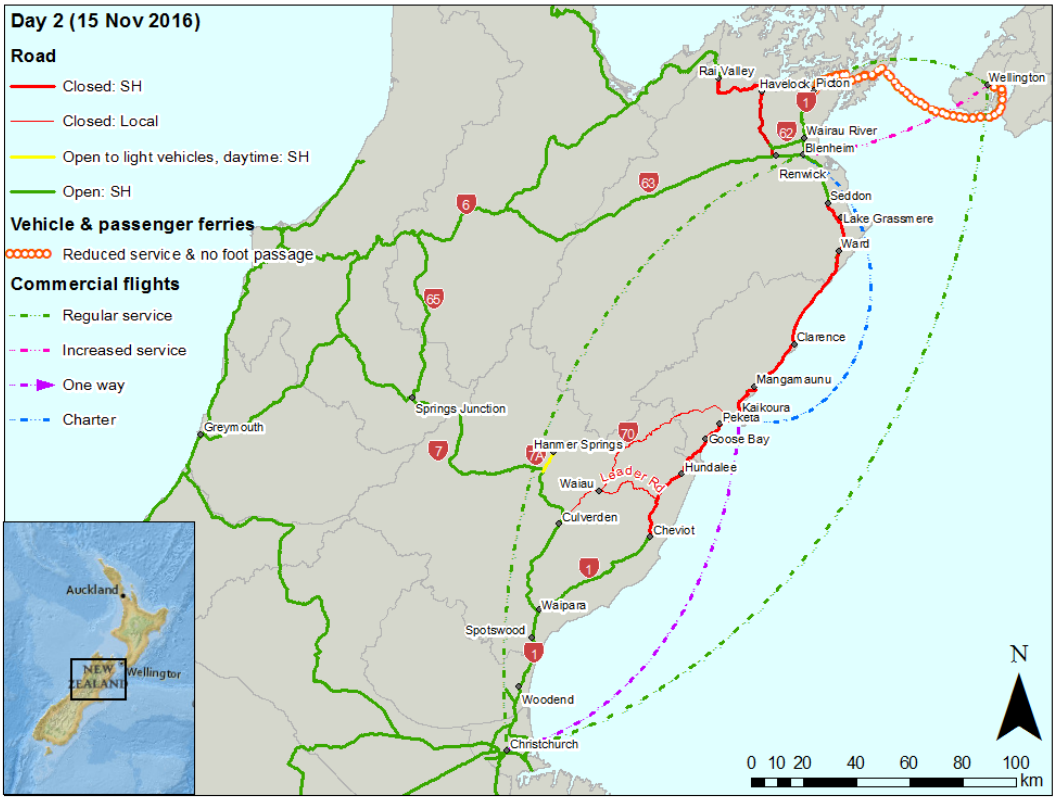

Figure 22. Level-of-service on Day 2 (15th November 2016).

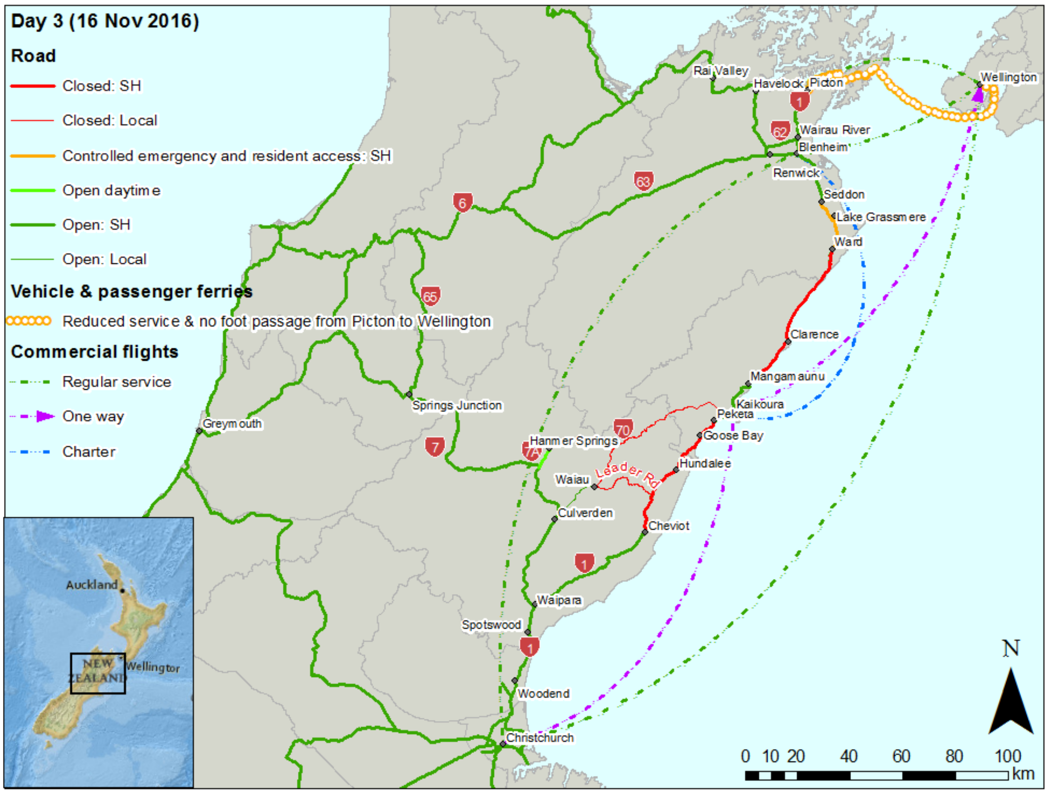

Figure 23. Level-of-service on Day 3 (16th November 2016).

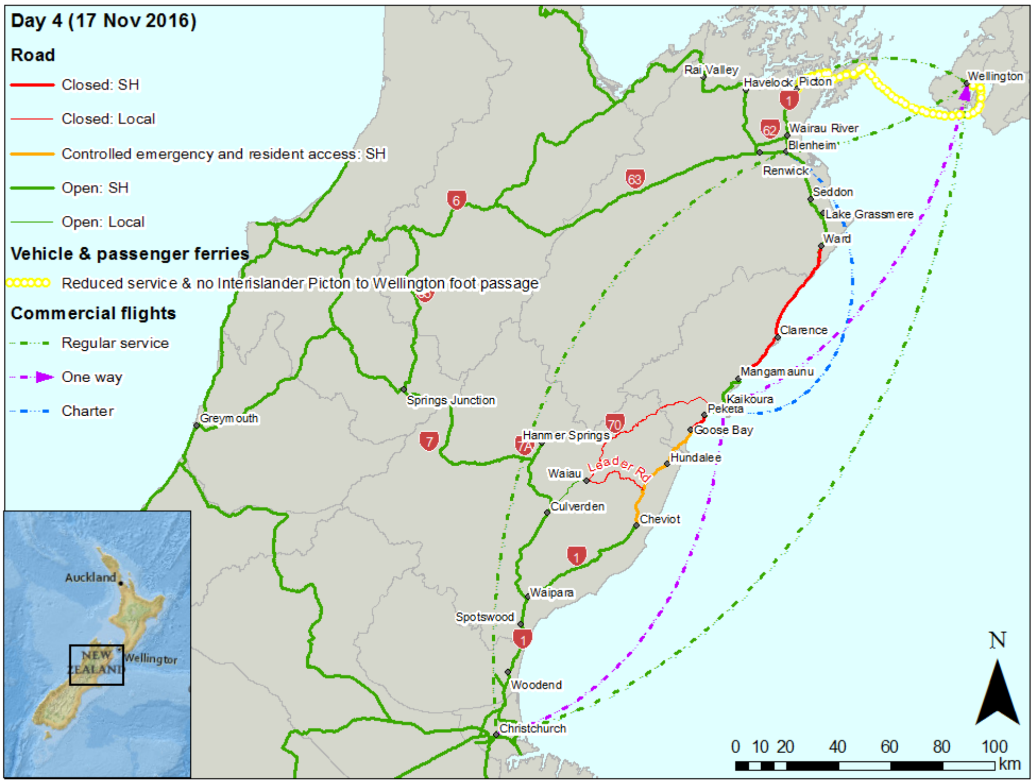

Figure 24. Level-of-service on Day 4 (17th November 2016).

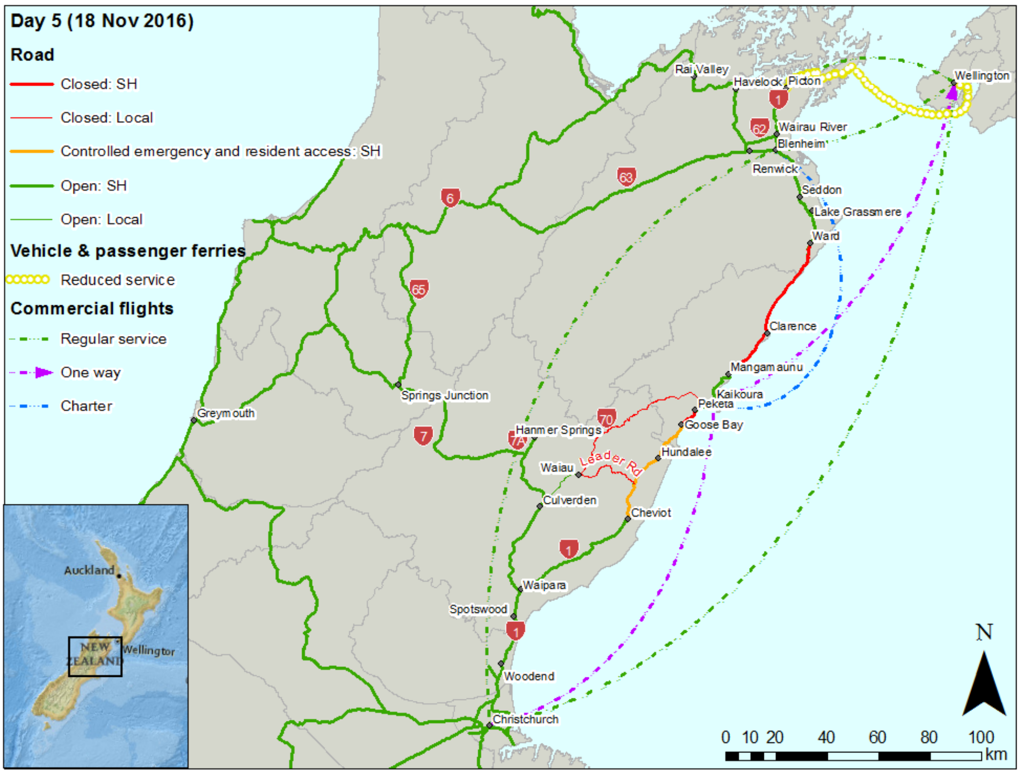

Figure 25. Level-of-service on Day 5 (18th November 2016).

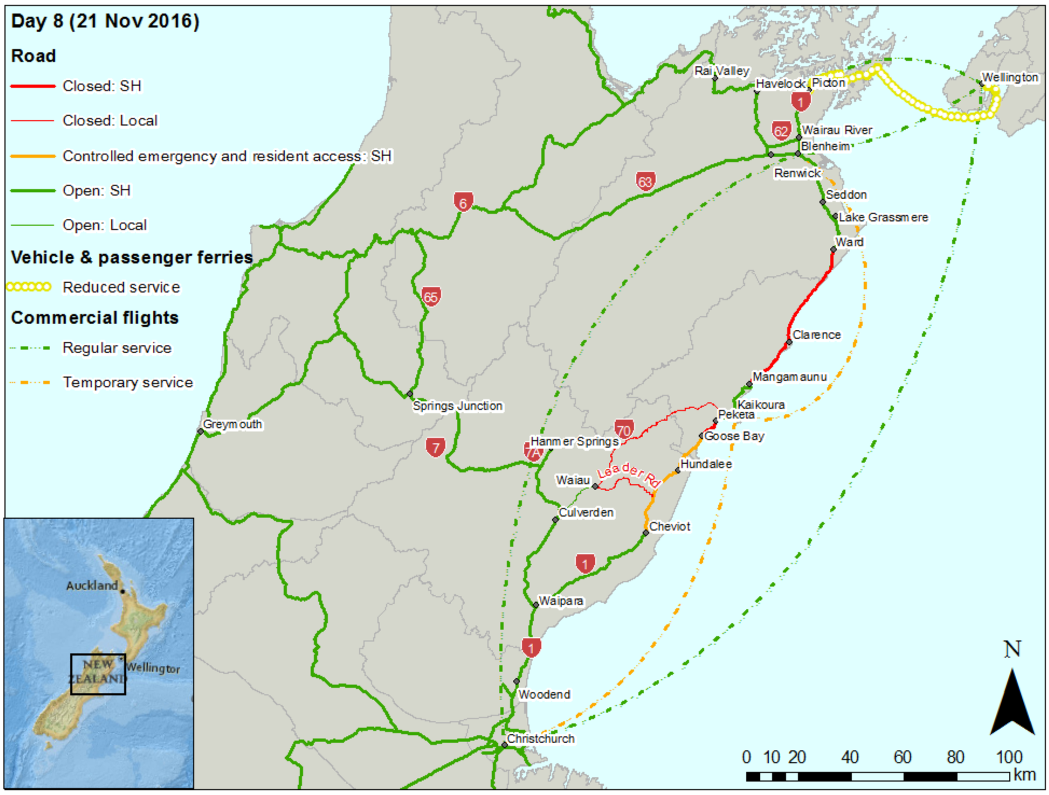

Figure 26. Level-of-service on Day 8 (21st November 2016).

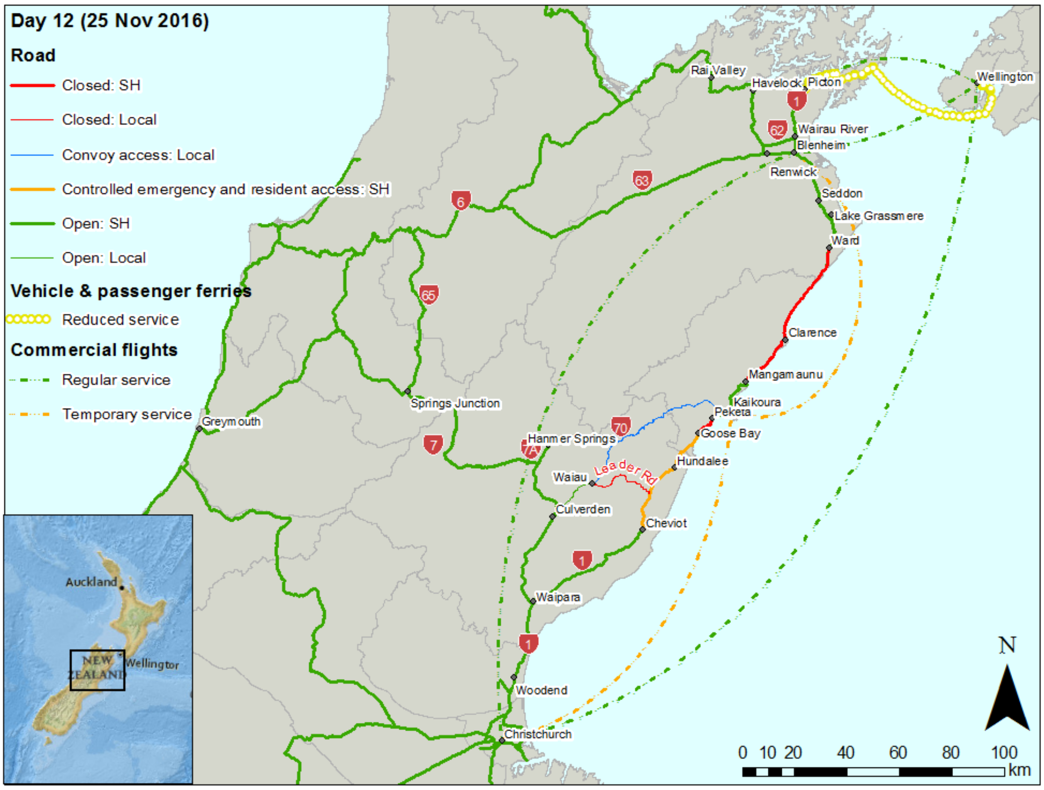

Figure 27. Level-of-service on Day 12 (25th November 2016).

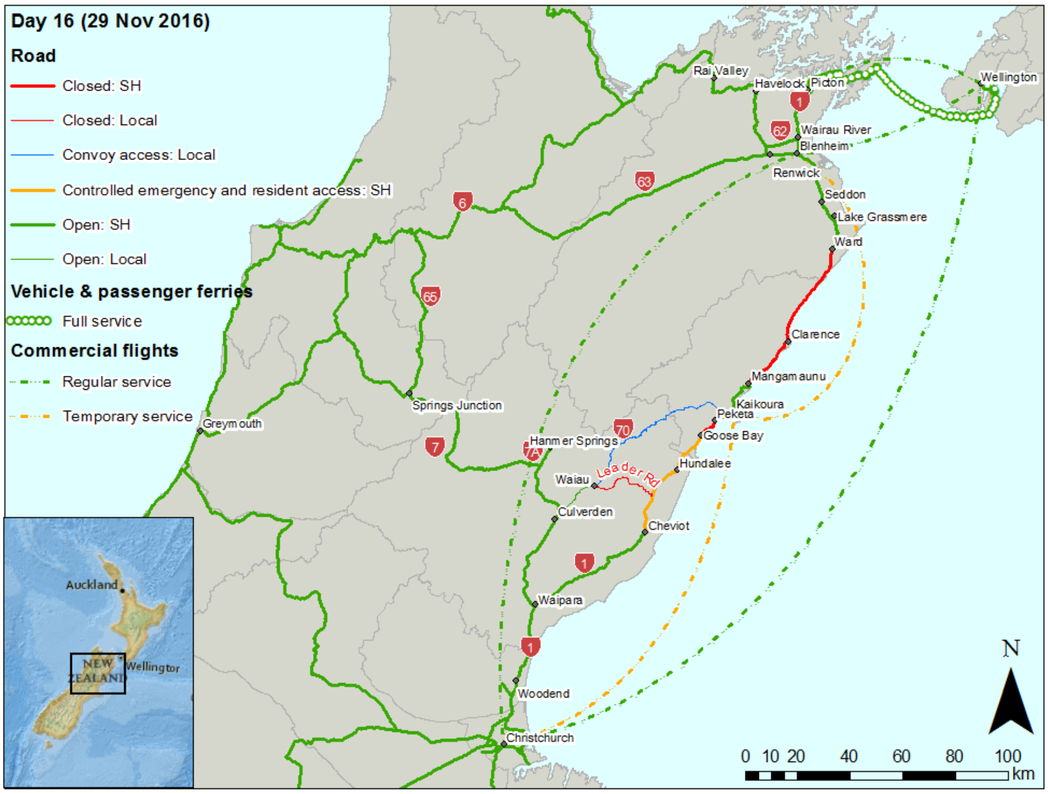

Figure 28. Level-of-service on Day 16 (29th November 2016).

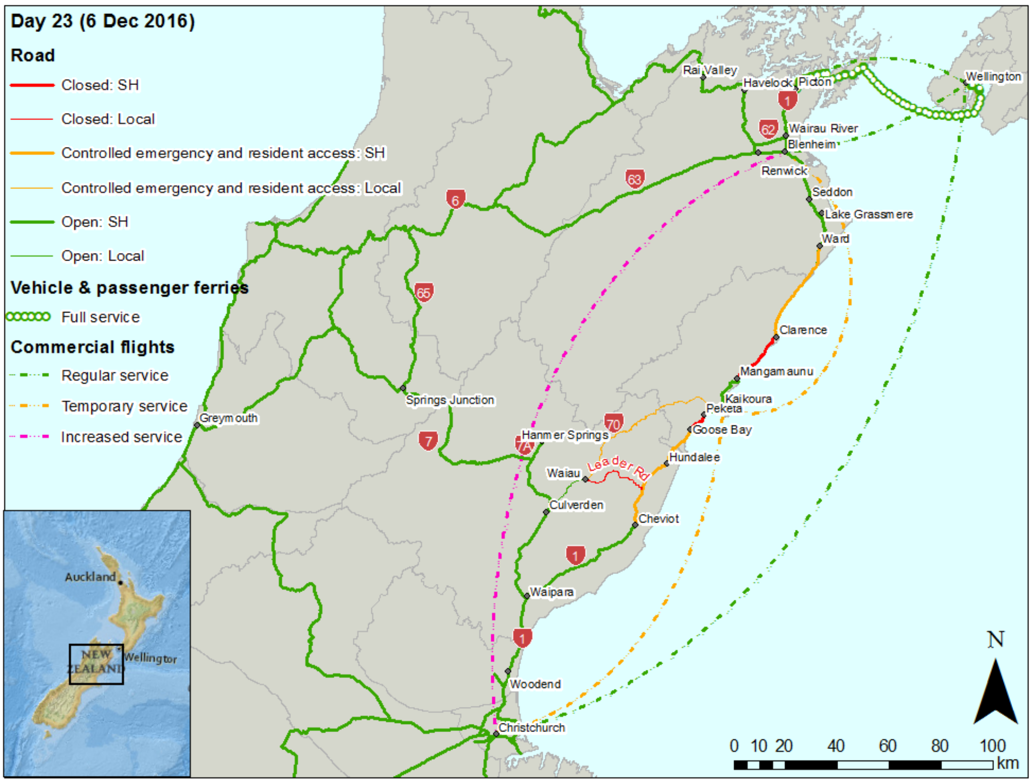

Figure 29. Level-of-service on Day 23 (6th December 2016).

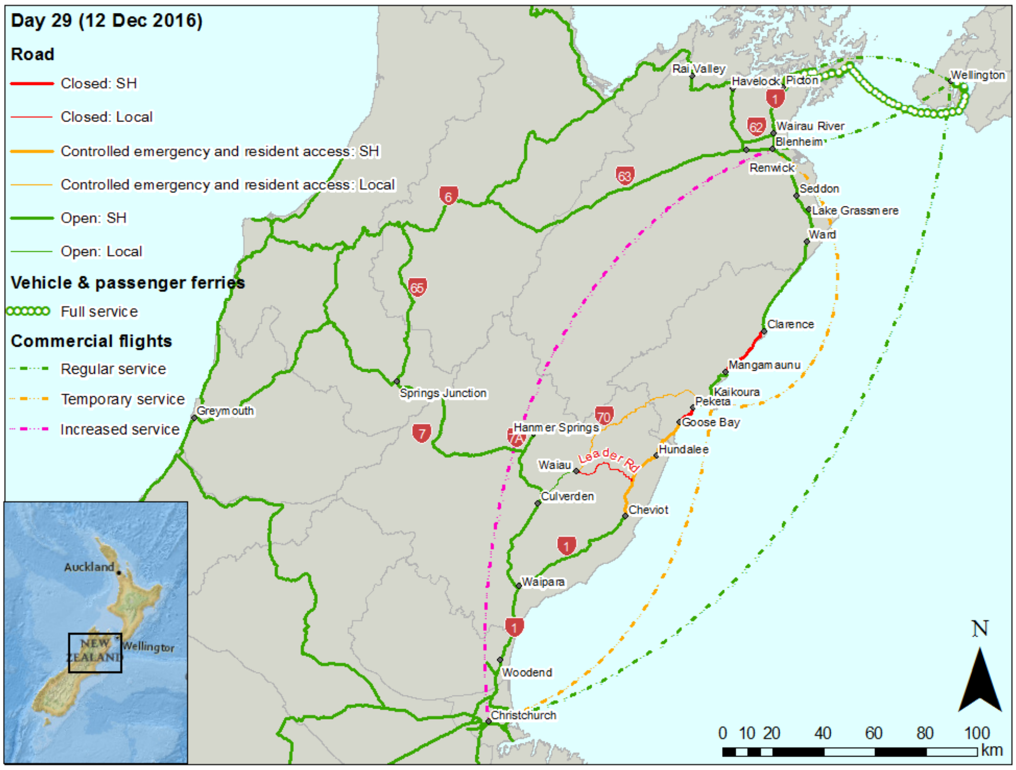

Figure 30. Level-of-service on Day 29 (12th December 2016).

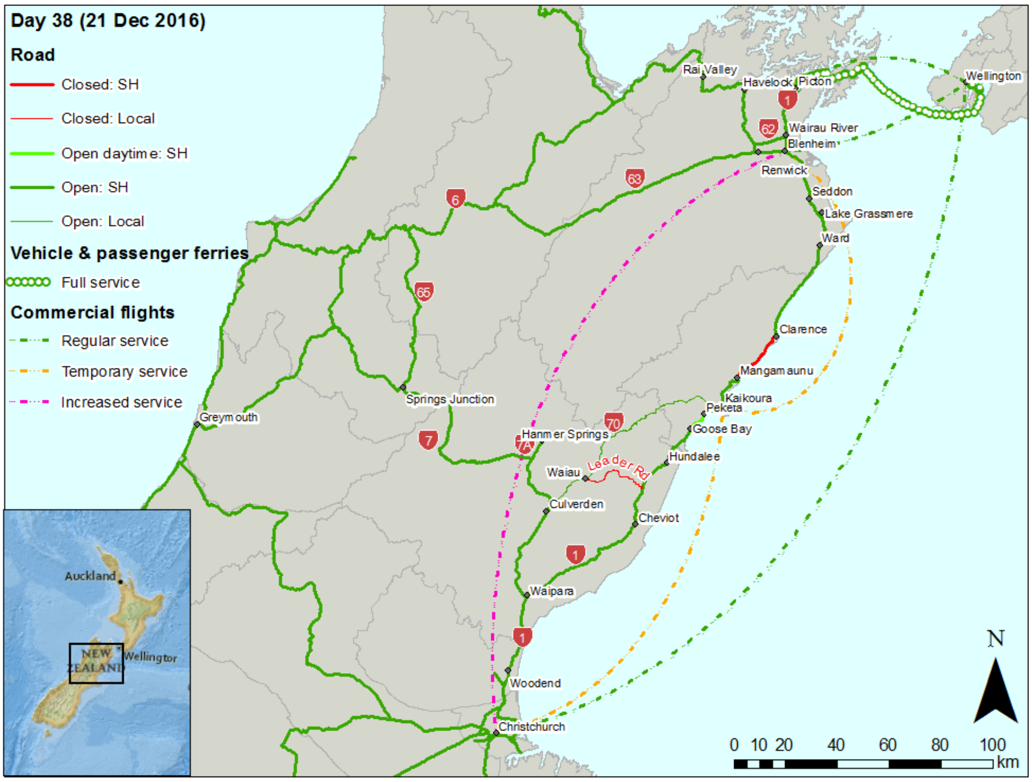

Figure 31. Level-of-service on Day 38 (21st December 2016).

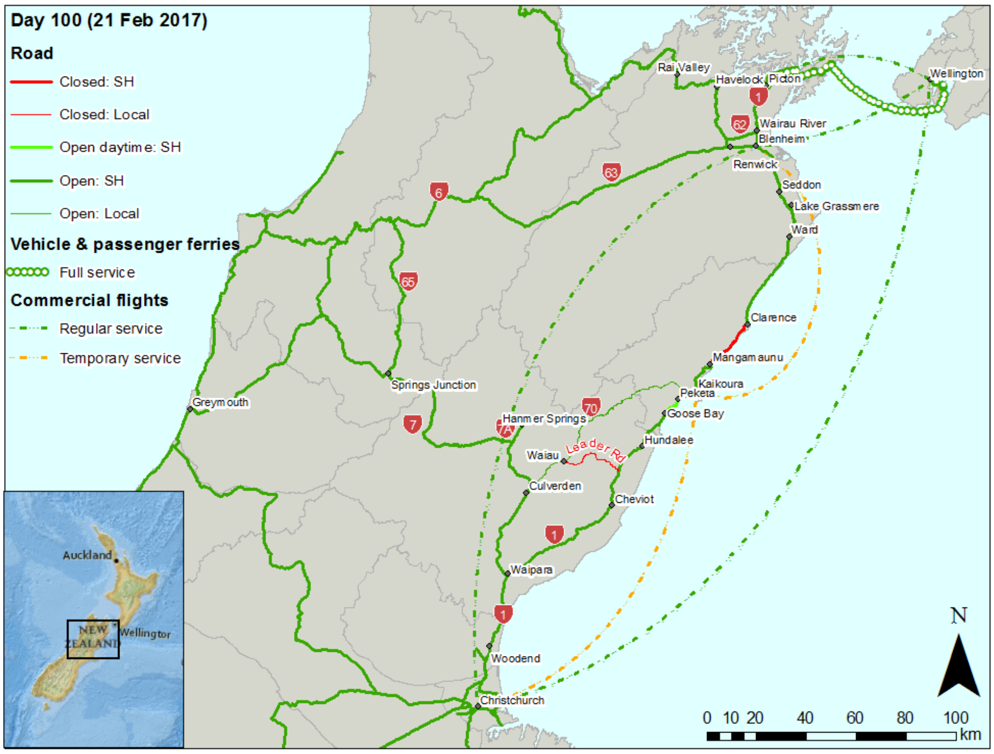

Figure 32. Level-of-service on Day 100 (21st February 2017).

3.5.3.2 Level-of-service mapping for rail lines carrying freight goods only, the rail component of the Aratere rail-enabled Interislander ferry, and official KiwiRail diversions.

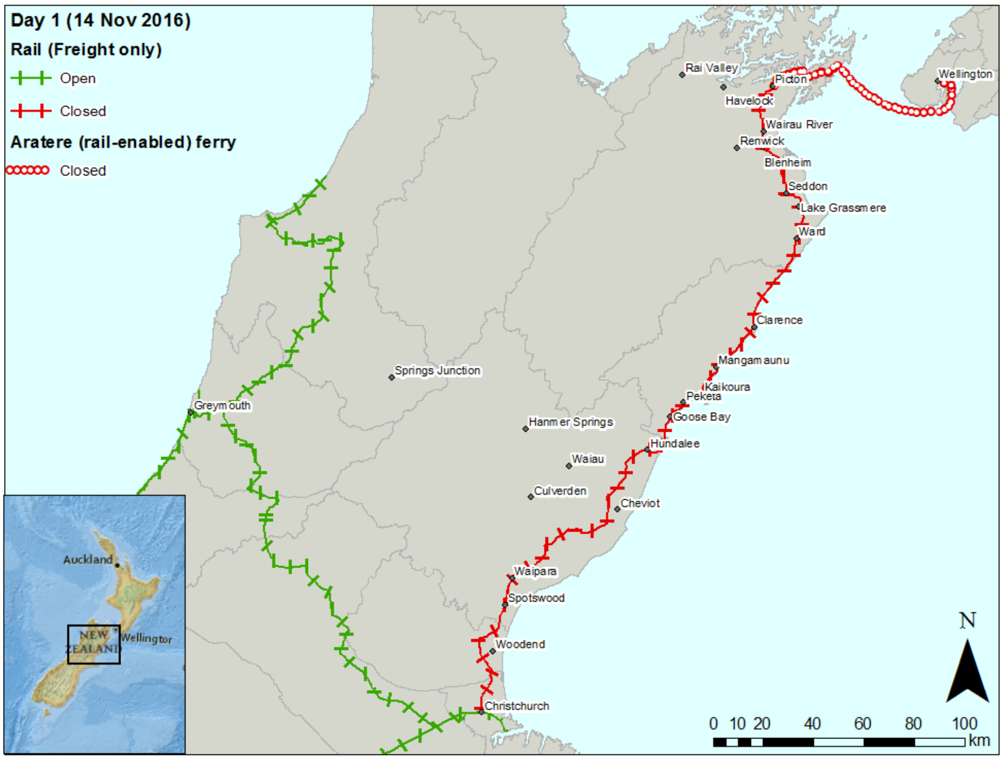

Figure 33. Rail level-of-service on Day 1 (14th November 2016).

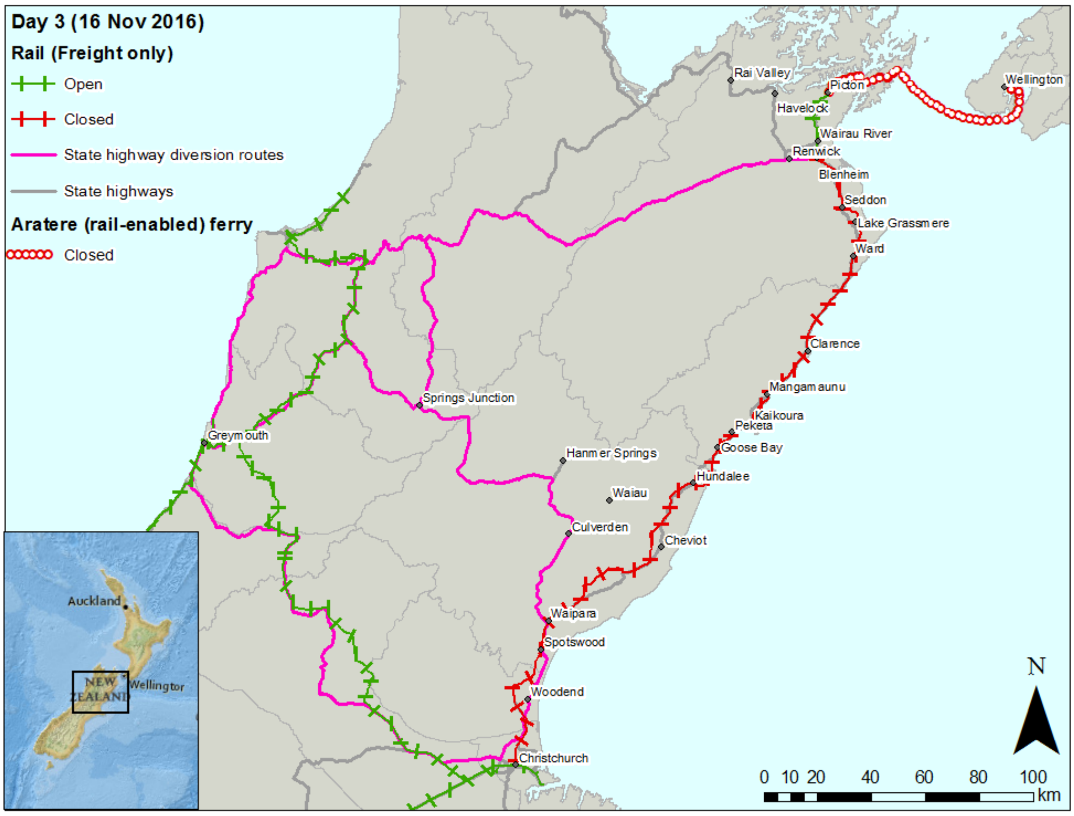

Figure 34. Rail level-of-service on Day 3 (16th November 2016).

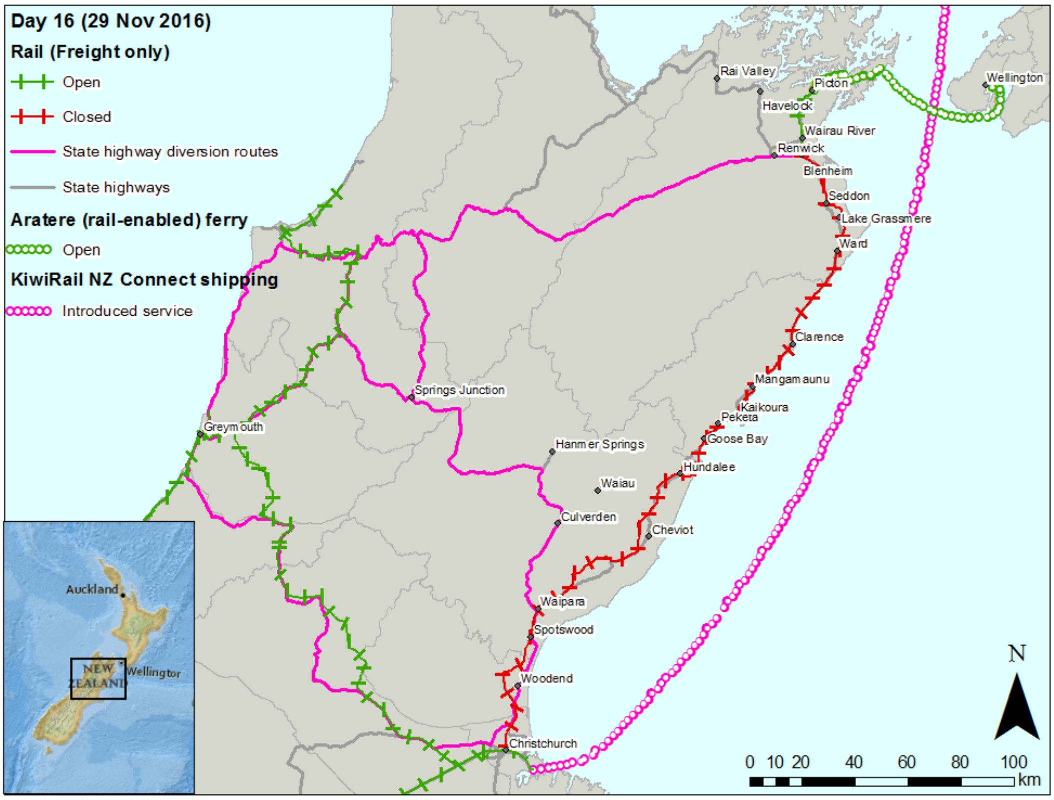

Figure 35. Rail level-of-service on Day 16 (29th November 2016).

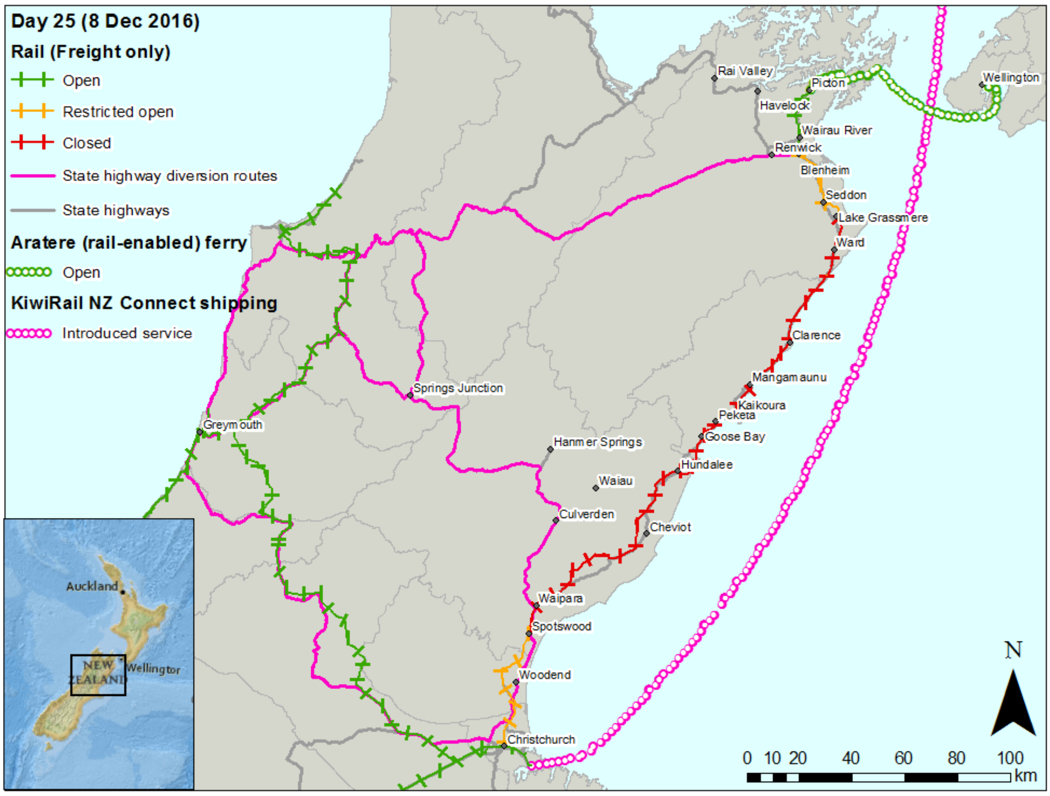

Figure 36. Rail level-of-service on Day 25 (8th December 2016).

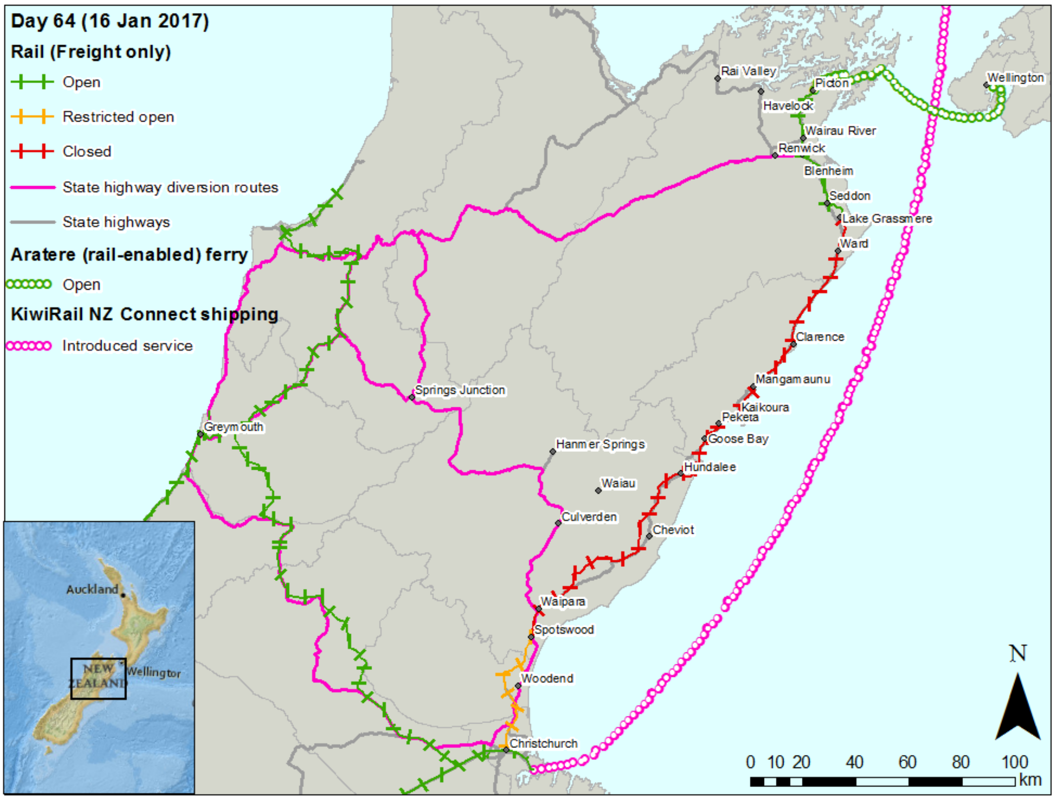

Figure 37. Rail level-of-service on Day 64 (16th January 2016).

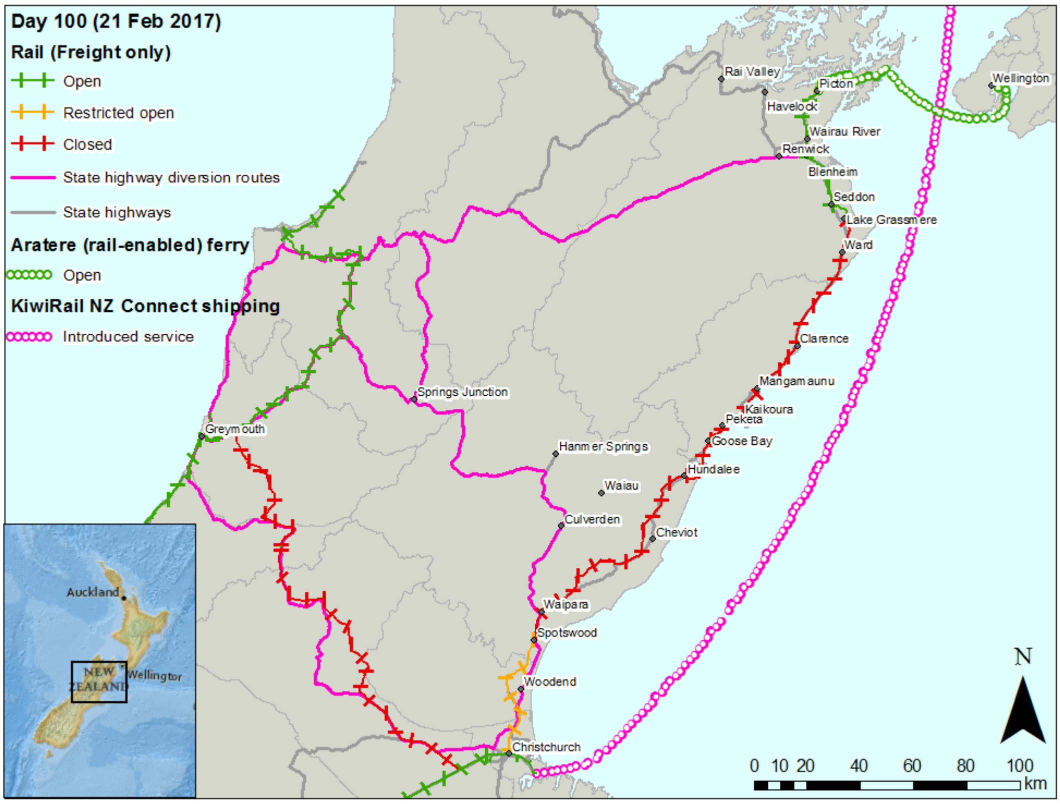

Figure 38. Rail level-of-service on Day 100 (21st February 2017).

3.6 Discussion

3.6.1 National and regional response and resilience

From the national and regional economy perspective, the earthquake was severe due to the damage to distributed infrastructure, particularly transportation networks: immediately following the earthquake, SH1 was closed between Waipara and Wairau River township, SH7 (including SH7A) was closed between Waipara and Springs Junction, increasing the travel time between Christchurch and Picton from around 3½ hours to more than 8 hours (Figure 20), all rail services between Palmerston North (North Island, north of Wellington) and Christchurch were suspended (Figure 33), and Picton and Wellington ports were closed, closing the main sea link between the South and North islands. This caused regional impacts, particularly disrupting supply chains (Market Economics, 2017). However, although there was still substantial strain on the transportation network, by the end of Day 1 access had greatly improved (Figure 21). SH1 had reopened from Waipara to Cheviot and SH7 had reopened between Waipara and Springs Junction (including daytime access along SH7A to Hanmer Springs), meaning the travel time between Christchurch and Picton became around 6½ hours. All ports were functioning (some at reduced capacity), and alternative cargo transport routes (by air, ferry, and road) remained. By Day 2, extra passenger flights were also being arranged where the usual transport capacity had been reduced below pre-earthquake levels, both between North Island and South Island locations, and between South Island locations (Figure 22).

The event evidenced strong resilient characteristics of the New Zealand transport network, highlighting the value of resilient design, interdependency planning, mutual assistance agreements, and highly trained, adaptable and scalable human resources, encouraged by New Zealand’s strong lifelines culture. While the continued closure of critical sections of the country’s main highway, SH1, and in particular the loss of rail freight transport along the MNL railway line between Picton and Christchurch, have caused a major national issue in the aftermath of the earthquake, cross-network interdependencies and service provider adaptability have ensured continued transport of goods and people since Day 1. Air and sea transport increased capacity quickly, both for emergency response and to ensure routine transport of goods continued as rail services were substantially reduced. Road transport has been diverted, and although subsequently delayed, has remained operable under increased traffic flows due to the availability of alternative routes and rapid deployment of response measures (Section 3.5.2.1), facilitating further usage increase from rail diversions. Although these alternative routes are under heavy pressure, these outcomes suggest the NIU’s focus on interdependency resilience and whole-of-system improved service, rather than asset, resilience is, at least to a degree, being achieved (Section 3.3.1).

However, whether the current level of regional resilience is acceptable, especially given the unreliability of air and sea travel (Section 3.5.1.1), remains an important consideration. The rapid deployment of a number of response measures facilitated the SH7, SH65, SH6 and SH63 alternative route to provide sufficient redundancy, but the South Island remains vulnerable as the SH6 section of the alternative route is currently the only route connecting Canterbury, the West Coast, Southland and Otago to the North Island through Picton and Wellington, a problem highlighted by the relative ease by which other state highways have been closed by weather and fire events in recent months within the South Island alone (Section 3.5.2.1). Additionally, the impact to KiwiRail caused by the closure of one rail line has been immense (Section 3.5.2.2). The rail network is at present entirely dependent on shipping and road to operate. Without Government ownership and funding, including establishing NCTIR, the ongoing viability of the rail network would have been questionable; it is worth noting the resilience the government has added in this event.

It is also worth noting that the negative impacts of this event have been reduced by circumstance. While the event caused no transport-related deaths or injuries, had this event occurred during daytime, this almost certainly would not have been the case. Additionally, in the 100 days after the event, the aftershock sequence caused relatively few transportation impacts, allowing for a swifter response and recovery operation. The event also uplifted the land relative to the sea by 1-2 m, itself increasing resilience to future coastal hazards, and reducing damage caused by the tsunami which followed the earthquake (further reduced because the event happened between mid and low tide) (Daly, 2017).

This event has highlighted the vulnerability of New Zealand’s regional transportation networks, which have limited or no redundancy in some cases. It is critical to address this issue in the area affected, and in other equally vulnerable regions. High-functioning alternative route redundancy, which can perform if another route or line is damaged (an area NZ Transport Agency had already identified as requiring improvement; Section 3.3.2), is evidently needed (New Zealand Transport Agency, 2014; Wilson et al., 2016). Using the road diversion as an example, while the longer route and increased volumes of traffic inevitably increased travel times, travel times along the alternative route could have been improved by pre-event measures including strengthening the pavement to cope with heavier truck loads, placing sufficient passing bays for high volumes of traffic, and building two-way traffic bridges at locations that could become bottlenecks under high traffic flows, instead of implementing these measures post-earthquake (Section 3.5.2.1).

3.6.2 Local response and resilience

The damage to land transport networks caused direct local impacts, including acute isolation of communities. However, the effective response to regional transport challenges allowed CDEM to quickly prioritise access to isolated settlements.

Road access to Kaikōura was first restored through Route 70, due to the heavier damage sustained by SH1. This local road, owned by Hurunui and Kaikōura district councils (Figure 9), was managed by Canterbury CDEM in conjunction with NZ Transport Agency under the declared State of Emergency, as an alternative to the damaged (and closed) state highway. Road management was a balancing act between three priorities: 1. repair of the road; 2. (emergency) supplies for and evacuation from Kaikōura; and 3. access for residents (including farmers). Effective management and operation was critical but challenging as prioritisation of any of the factors slowed down the other two, and the organisational arrangement had never previously been exercised. This led to some (short) operational delays and inconsistent public messaging. NZ Transport Agency took full control of managing Route 70 on Day 16 (29th November 2016), and singularly managed the road until Day 38, when the Government announced NCTIR, which assumed responsibility for the rebuild of SH1, Route 70 and the MNL rail corridor.

While all settlements had road access by Day 23, CDEM currently advises residents to be prepared with 7 days of emergency supplies. Although helicopter and (to some extent) sea access were sufficient during this event, the event also highlighted the unreliability of these modes of emergency transport (Section 3.5.1.1). This evidence, along with scenarios being produced for other potential hazardous events, such as an Alpine Fault rupture scenario that suggests air response may be limited (Robinson et al., 2015), mean the length of time without road access seen in Kaikōura could be a realistic example of the length of time people should be prepared to be isolated for. This highlights the importance of preparedness, and the gap between recommendations and expected future events.

3.7 Conclusion

With increasing reliance on transport networks for vital services, such as just-in-time food and other fast-moving consumer goods delivery, the need for a resilient transport network has never been greater. From the national and regional economy perspective, the 14th November 2016 M_w 7.8 earthquake was severe due to the damage to distributed infrastructure, and particularly transportation networks. 100 days after the event, sections of New Zealand’s main highway, State Highway 1 (SH1), and the Main North Line (MNL) railway line between Picton and Christchurch (Figure 9) remain closed and the major consequential issue still facing New Zealand. However, cross-network interdependencies and service provider adaptability have ensured continued regional transport of goods and people since Day 1, and this effective response to regional transport challenges allowed CDEM to quickly prioritise access to isolated settlements.

This earthquake, alongside coincident events (such as severe weather and rural fires), highlighted the need for well-practiced, efficient responses; major strengthening and engineering structures along critical transport routes; and high-functioning alternative route redundancy, which can perform if another route or line is damaged. This work needs to be evidence-based and should take a holistic view of the essential nature of transportation infrastructure. Settlements were also without road access for 23 days, raising questions of the validity of current CDEM generic advice that residents nationally should be prepared with 7 days of emergency supplies. In rural and potentially isolated communities, advising preparation for a longer period appears necessary.

Much of the groundwork for a resilient transport network was evidenced by this event, but it is important to learn from this, as well as from similar events experienced around the world. This earthquake has highlighted the vulnerability of New Zealand’s distributed infrastructure networks, which have little or no redundancy throughout the country. Ensuring the services provided by distributed infrastructure can remain functional after a natural hazard is a critical challenge in order to ensure the future viability of the country, which will face multiple known hazards, some of which will be of greater magnitude than this event, in the future.

3.8 Acknowledgments

We are thankful to NZ Transport Agency, KiwiRail and Canterbury CDEM for providing data for this paper. We gratefully acknowledge GNS Science, KiwiRail, Tonkin & Taylor, Aurecon, Dizhur & Giaretton, and Tim Little for providing images used in this paper. The financial support of the Earthquake Commission (EQC), GNS Science (GNS), the Resilience to Nature’s Challenges National Science Challenge and QuakeCoRE is gratefully acknowledged. We are grateful to NZ Transport Agency, KiwiRail, CentrePort, SoundsAir, Canterbury, Marlborough and Wellington CDEM, Marlborough District Council, Kaikōura District Council, Hurunui District Council and Waimakariri District Council for their regular public updates which have contributed to this paper.

3.9 References

Bartlett, H 2017, *Building bridges to get over traffic issues on Kaikoura alternative route*, viewed 12/03/17, http://www.stuff.co.nz/dominion-post/news/national/89250771/Building-bridges-to-get-over-traffic-issues-on-Kaikoura-alternative-route.

Bradley, B, Comerio, M, Cubrinovski, M, Dellow, S, Dizhur, D, Elwood, K, Giaretton, M, Green, R, Horspool, N, Hughes, M, Ingham, J, Johnson, L, Massey, C, Seville, E, Simkin, G, Stevenson, J, Wilson, R & Wotherspoon, L 2017, Earthquake Reconnaissance Report: M7.8 Kaikoura, New Zealand Earthquake on November 14, 2016', QuakeCoRE, GEER, and EERI, Christchurch, New Zealand, 24pp.

Bridges, S 2016a, *Alliance established to rebuild Kaikōura coastal route*, viewed 27/14/17, https://www.beehive.govt.nz/release/alliance-established-rebuild-kaikoura-coastal-route.

Bridges, S 2016b, *Government to reinstate Kaikōura coastal route*, viewed 27/04/17, https://www.beehive.govt.nz/release/government-reinstate-kaikoura-coastal-route.

Buick, A 2017, *New Bridges on SH 63 to ease traffic*, viewed 12/4/17, http://nelsonlive.co.nz/2017/02/new-bridges-on-sh-63-to-ease-traffic/.

Cropp, A 2016, *Plans to fast track deepening of Kaikōura marina*, viewed 3/11/18, http://www.stuff.co.nz/business/86772819/plans-to-fast-track-deepening-of-kaikoura-marina.

Cubrinovski, M, Bray, J, de la Torre, C, Olsen, M, Bradley, B, Chiaro, G, Stock, E & Wotherspoon, L 2017, 'Liquefaction effects and associated damages observed at the Wellington CentrePort from the 2016 Kaikoura earthquake', *Bulletin of the New Zealand Society for Earthquake Engineering,* vol. 50, no. 2, pp. 152-173.

Daly, M 2017, *Kaikōura Earthquake tsunami was as high as 7 metres at one spot*, viewed 27/04/17, http://www.stuff.co.nz/national/90773348/kaikoura-earthquake-tsunami-was-as-high-as-7-metres-at-one-spot.

Davies, T, Davies, A & Hughes, M 2016, *Building transport resilience for the inevitable future disasters*, viewed 16/03/17, http://www.stuff.co.nz/national/nz-earthquake/87053620/building-transport-resilience-for-the-inevitable-future-disasters.

Dellow, S, Massey, C, Cox, S, Archibald, G, Begg, J, Bruce, Z, Carey, J, Davidson, J, Della Pasqua, F & Glassey, P 2017, 'Landslides caused by the Mw7. 8 Kaikōura earthquake and the immediate response', *Bulletin of the New Zealand Society for Earthquake Engineering,* vol. 50, no. 2, pp. 106-116.

DPMC 2015, *The Guide to the National Civil Defence Emergency Management Plan 2015*, Ministry of Civil Defence & Emergency Management, The Department of the Prime Minister and Cabinet, Wellington, New Zealand.

Eder, J 2016, *New speed limits for alternative Picton to Christchurch highway*, viewed 12/03/17, http://www.stuff.co.nz/national/87848488/New-speed-limits-for-alternative-Picton-to-Christchurch-highway.

Eder, J 2017, *Looters describe finding Kaikoura train after earthquake*, viewed 4/4/17, http://www.stuff.co.nz/national/89916837/looters-describe-finding-kaikoura-train-after-earthquake.

Fenwick, A 2012, *The Value of Lifeline Seismic Risk Mitigation in Christchurch: Summary Report, June 2012*, New Zealand Lifelines.

Giovinazzi, S, Wilson, T, Davis, C, Bristow, D, Gallagher, M, Schofield, A, Villemure, M, Eidinger, J & Tang, A 2011, 'Lifelines performance and management following the 22 February 2011 Christchurch earthquake, New Zealand: highlights of resilience', *Bulletin of the New Zealand Society for Earthquake Engineering,* vol. 44, no. 4, pp. 402-417.

Hamling, IJ, Hreinsdóttir, S, Clark, K, Elliott, J, Liang, C, Fielding, E, Litchfield, N, Villamor, P, Wallace, L, Wright, TJ, D’Anastasio, E, Bannister, S, Burbidge, D, Denys, P, Gentle, P, Howarth, J, Mueller, C, Palmer, N, Pearson, C, Power, W, Barnes, P, Barrell, DJA, Van Dissen, R, Langridge, R, Little, T, Nicol, A, Pettinga, J, Rowland, J & Stirling, M 2017, 'Complex multifault rupture during the 2016 Mw 7.8 Kaikōura earthquake, New Zealand', *Science,* vol. 356, no. 6334.

Jenkins, H 2016, *Temporary Restricted Area in Place for Kaikōura*, viewed 12/04/17, https://airshare.uberflip.com/news-hub-articles/temporary-restricted-area-in-place-for-kaikoura.

Kilroy, S 2017, *Bridge demolition about to begin*, viewed 12/04/17, http://www.kiwirail.co.nz/news/464/130/Bridge-demolition-about-to-begin.html.

KiwiRail 2016, *KiwiRail Annual Integrated Report 2016*, Wellington, New Zealand.

Lamb, J 1997, *Risks & Realities: A Multi-disciplinary Approach to the Vulnerability of Lifelines to Natural Hazards*, Centre for Advanced Engineering, University of Canterbury.

Lewis, O 2016a, *Marlborough airline Sounds Air launches new service to Kaikōura*, viewed 16/03/17, http://www.stuff.co.nz/business/86606248/Marlborough-airline-Sounds-Air-launches-new-service-to-Kaikoura.

Lewis, O 2016b, *Sounds Air offers additional Christmas flights as travellers look to avoid inland bypass*, viewed 12/03/17, http://www.stuff.co.nz/travel/news/87195215/sounds-air-offers-additonal-christmas-flights-as-travellers-look-to-avoid-inland-bypass.

Market Economics 2017, *Economic impact of the 2016 Kaikōura earthquake: A report prepared for the Ministry of Transport*, viewed 28/04/17, http://www.mbie.govt.nz/publications-research/publications/economic-development/economic-impact-2016-kaikoura-earthquake.pdf.

Mattinbgn 2011, *A rock fall shelter and aqueduct on the Arthurs Pass section of New Zealand State Highway 73, near Otira, New Zealand*, viewed 12/04/17, https://commons.wikimedia.org/wiki/User:Mattinbgn/gallery_003#/media/File:Otira_Rock_Fall_Shelter_%26_Aqueduct.JPG.

MCDEM 2002, *Civil Defence Emergency Management Act 2002*, New Zealand Government Ministry of Civil Defence & Emergency Management, Wellington, New Zealand.

Ministry of Transport 2011, *Connecting New Zealand: A summary of the government's policy direction for transport*, Ministry of Transport, Wellington, New Zealand.

National Infrastructure Unit 2015, *The Thirty Year New Zealand Infrastructure Plan 2015*, New Zealand Government, Wellington, New Zealand.

New Zealand Lifelines Committee n.d., *New Zealand Lifelines Brochure*, viewed 23/03/17, http://www.civildefence.govt.nz/assets/Uploads/publications/nzlc-brochure.pdf.

New Zealand Transport Agency 2014, *State Highway Network Resilience National Programme Buisness Case*, New Zealand Transport Agency, Wellington, New Zealand.

Nicol, A, Benson, A, Bischoff, A, Hatem, A, Barrier, A, Villamor, P, Nicol, A, Wandres, A, Lukovic, B, Hall, B, Gasston, C, Margetts, C, Asher, C, Grimshaw, C, Madugo, C, Fenton, C, Hale, D, Barrell, D, Heron, D, Strong, D, Townsend, D, Noble, D, J, H, Pettinga, J, Kearse, J, Williams, J, Bensing, J, Manousakis, J, Borella, J, Mountjoy, J, Rowland, J, Clark, K, Pedley, K, Sauer, K, Berryman, K, Hemphill-Haley, M, Stirling, M, Villeneuve, M, Cockroft, M, Khajavi, N, Griffiths, N, Barnes, P, Villamor, P, Carne, R, Langridge, R, Zinke, R, van Dissen, R, McColl, S, Cox, S, Lawson, S, Little, T, Stahl, T, Cochran, U, Toy, V, Ries, W, Juniper, Z, Mouslopoulou, V, Oncken, O, Begg, J, Hamlin, I, Kufner, S, Reid, C, Panagiotis, P, Kyritsis, S, Beetham, D, Kaiser, A, Balfour, N, Holden, C, Fry, B, Hamling, I, Horspool, N, McVerry, G, D’Anastasio, E, Gerstenberger, M, Bannister, S, Ristau, J, Van Houtte, C, Abbott, E, Hreinsdottir, S, Christophersen, A, Rhoades, D, Benites, R, Wotherspoon, L, Dellow, S, Rosser, B, Massey, C, della Pascua, F et al. 2016, 'Geology of the Kaikoura Earthquake'. Presentation, University of Canterbury, Christchurch, NZ.

O'Connell, T 2016, *Rainbow road State Highway 1 option floated*, viewed 16/03/17, http://www.stuff.co.nz/nelson-mail/86860201/rainbow-road-state-highway-1-option-floated.

Palermo, A, Liu, R, Rais, A, McHaffie, B, Andisheh, K, Pampanin, S, Gentile, R, Nuzzo, I, Granerio, M & Loporcaro, G 2017, 'Performance of road bridges during the 14 November 2016 Kaikōura earthquake', *Bulletin of the New Zealand Society for Earthquake Engineering,* vol. 50, no. 2, pp. 253-270.

Radio New Zealand 2017, *Insight: Keeping NZ Rail on the Tracks*, viewed 26/04/17, http://www.radionz.co.nz/national/programmes/insight/audio/201840329/insight-keeping-nz-rail-on-the-tracks.

Robinson, TR, Buxton, R, Wilson, TM, Cousins, WJ & Christophersen, AM 2015, 'Multiple infrastructure failures and restoration estimates from an Alpine Fault earthquake: Capturing modelling information for MERIT', *ERI Research Report,* vol. 2015, no. 4, p. 89.

Stats NZ 2013, *2013 Census QuickStats about a place: Christchurch City*, viewed 16/03/17, http://www.stats.govt.nz/Census/2013-census/profile-and-summary-reports/quickstats-about-a-place.aspx?request_value=14758&tabname=.

Stevenson, JR, Becker, J, Cradock-Henry, N, Johal, S, Johnston, D, Orchiston, C & Seville, EJBotNZSfEE 2017, 'Economic and social reconnaissance: Kaikōura earthquake 2016', *Bulletin of the New Zealand Society for Earthquake Engineering,* vol. 50, no. 2, pp. 346-355.

Stirling, MW, Litchfield, N, Villamor, P, Van Dissen, R, Nicol, A, Pettinga, J, Barnes, P, Langridge, R, Little, T & Barrell, DJBNZSEE 2017, 'The Mw 7.8 2016 Kaikōura earthquake: Surface fault rupture and seismic hazard context', *Bulletin of the New Zealand Society for Earthquake Engineering,* vol. 50, no. 2, pp. 73-84.

The Treasury 2016, *National State of Infrastructure Report 2016: Progress one year on from the Thirty Year New Zealand Infrastructure Plan*, National Infrastructure Advisory Board & the Treasury's National Infrastructure Unit, Wellington, New Zealand.

Wilson, TM, Davies, T & Robinson, TR 2016, *Earthquakes and landslides - Expert Q&A*, viewed 12/04/17, http://www.sciencemediacentre.co.nz/2016/11/17/earthquakes-and-landslides-expert-qa/.

4. The value of natural hazards scenario planning in increasing community disaster resilience: developing the AF8+ scenario for Franz Josef and the West Coast region, New Zealand

Note: Some of the material at the beginning of this chapter is repeated from Chapter 1 because this chapter forms the basis of a standalone paper.

4.1 Abstract

Collaboration to enable integrated disaster impact reduction decision-making has become a political, policy and practice priority. However, while the importance of participatory decision-making has been well recognised, the development of effective participatory approaches in practice has lagged far behind. In this paper, a transferrable scenario-based participatory approach is developed and applied, using a large-scale earthquake hazard event scenario, in a “pre-disaster” collaboration. Sequencing participatory methodologies within the scenario-based participatory approach allowed stakeholders to engage with and gain more influence over the process at their relevant scale (i.e. local, regional, or national), as well as enabling the process design to better suit the participation capacities of the stakeholder groups. This approach enabled community knowledge to be integrated and balanced with and alongside that of infrastructure providers, emergency managers, local government policymakers and researchers to proactively increase resilience to naturally-triggered disasters. The process demonstrated the ability to co-create knowledge which in turn can inform decision-making. Further, the process also directly increased the resilience of Franz Josef, New Zealand, and the resilience of distributed infrastructure networks by stakeholders actioning the developed shared understanding.

4.2 Introduction

Collaboration to enable integrated disaster impact reduction decision-making has become a political, policy and practice priority, for example, featuring in the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015). Although hazards and impacts may be regional, disasters are local events which first and foremost affect local communities (Gaillard & Mercer, 2013). This realisation has contributed to growing recognition of the need to involve community members in decision-making that affects their disaster resilience (Ackerman, 2004; Maskrey, 2011; Murphy et al., 2014; Pearce, 2003). The term “community” is often used to denote a group of people living or working in a geographic location, and particularly those who are involved to at least some extent in government or other administrative decision-making affecting the relevant location. However, this use of the term “community” has been critiqued on the grounds that it implies a homogeneity that does not exist in practice, meaning that so-called “community based” initiatives that assume this homogeneity risk overlooking existing conflicts and entrenching existing, inequitable power relations (e.g. Cannon, 2014). Acknowledging the validity of this critique, and the essentially heterogenous reality of any population, the term “community” is used in this article to refer to the varied group of people who are (or are likely to be) exposed to the same disaster impacts through social, spatial and/or immediate economic links (Appendix B).

The benefits of inclusive, participatory approaches have been well established, and include better quality decisions and better identification of vulnerabilities, as well as more empowerment of locals, greater perceptions that decisions are fair, reduced conflict, and increased trust in decision-makers (see Reed, 2008, for a summary). While the importance of participatory decision-making has been well recognised, the development of effective participatory approaches in practice has lagged far behind (Ackerman, 2004; Díez et al., 2015; Howard, 2018). Community participation involves substantial time and effort, when all stakeholders have limited time, resources and interest, restricting their capacity to participate in or facilitate additional activities (Reed et al., 2013). Further, while community members often participate in disaster impact reduction efforts, integrating and balancing the knowledge of community members with and alongside that of practitioners, policymakers and researchers remains rare and difficult (Ackerman, 2004; Aoki, 2018; Broad et al., 2007; Cooke & Kothari, 2001; Pearce, 2003; van der Vegt, 2017). Unbalanced participation reduces opportunities for knowledge integration and, moreover, can reinforce existing privileges (Cooke & Kothari, 2001; Nelson & Wright, 1995), reduce trust (which must be earned) in the process and/or facilitator (Eiser et al., 2012; Ravera et al., 2011; Reed, 2008), and cause engagement fatigue and disillusionment (Burton et al., 2004; Cooke, 2004; Reed, 2008; Wondolleck & Yaffee, 2000), all of which discourage (future) participation.

When developing participatory decision-making approaches, methodological advances have also not been well documented and so have not been well used, partly due to the abundance of participation methodologies being developed (Fung, 2006; Rowe & Frewer, 2005; van der Vegt, 2017). Typologies have been used to clarify key participatory methodological elements since the early and influential 'ladder of citizen participation' (Arnstein, 1969, p. 217). Aoki (2018) provides one of the most recent and comprehensive typologies, by adapting the Fung (2006) typology through both a literature review and through learnings from a case study of a post-disaster recovery process in the remote Japanese community of Onagawa, Japan, where community members and government experts shared decision-making responsibilities. However, Aoki (2018) found that sequencing participation allows different stakeholder groups to participate more intensely at different stages during the overall process, focussing on relevant areas. This helps to ensure that "solutions" which are not technically or financially feasible and so can undermine trust, are not proposed.

In this doctoral project, for example, community members had more influence on assessments of potential disaster impacts on the community, but less influence on assessments of technical infrastructure restoration times (over which infrastructure providers gain more influence). This made it possible for community members to influence decisions concerning infrastructure restoration priorities. Sequencing participation also helped to overcome barriers to participation by reducing the time commitment required from each stakeholder group, as discussions of most interest to individual stakeholder groups could be held without requiring all involved to participate. This also helped to constrain and ensure credibility, reducing the potential for confusion caused by non-experts debating and speculating about needs and outcomes they know little about. For example, network infrastructure providers may have little knowledge of community post-disaster needs, while community members do not have access to network restoration times.

While all communities benefit from participating in disaster impact reduction efforts to some extent, this participation is essential for remote communities at risk of isolation due to disaster impacts (Chapter 2). Although specific definitions vary, most countries use (small) size, and distance from essential services (e.g. hospitals) and urban centres (geographic remoteness) when categorising the ‘remoteness’ of regions and communities (e.g. Fiji Bureau of Statistics, n.d.; SARRAH, n.d.; Statistics Canada, n.d.; Stats NZ, n.d.). Community members in remote locations are relied upon to implement disaster resilience. This reliance has been driven by the need for cost efficiency and by pragmatism in some countries (Remling & Veitayaki, 2016), and is usually required because if isolated, community members in remote communities must lead immediate response efforts in the absence of input from authorities (Gardner, 2015; Orchiston, 2013). A growing body of evidence indicates that if community members are not involved in disaster governance, or do not trust the outcomes, they are not likely to implement the proposed disaster impact reduction measures (Eiser et al., 2012; Ellemor, 2005; Murphy et al., 2014). Therefore, for a disaster impact reduction initiative to succeed in a remote community, community members must adopt and take ownership of the initiative (Chapter 2; Remling & Veitayaki, 2016).

This paper is situated at the intersection between research and practice fields concerned with remote communities, distributed infrastructure, emergency management and hazard science. It reports on the development of a transferrable scenario-based participatory approach, using a large-scale earthquake hazard event scenario, and its application in a remote community, through a collaboration between community members in Franz Josef, New Zealand, infrastructure providers, emergency managers, local government policymakers and researchers.

In this paper, we attempt to answer the following research questions:

1. What is required to develop an effective participatory process which integrates local knowledge, technical knowledge and hazard impact science, in a balanced collaboration, for disaster impact reduction?
2. How might such a participatory approach integrate ongoing participant outputs as inputs, to ensure that disaster impact reduction efforts continue to iteratively build on improvements in shared understanding?
3. What is required to create a transferrable participatory approach for disaster impact reduction?

To answer these research questions, we:

1. Develop a transferrable participatory approach for disaster impact reduction by combining and sequencing participation methodologies.

2. Apply this scenario-based participatory approach in a “pre-disaster” collaboration between community members, infrastructure providers, emergency managers, local government policymakers and researchers to:
    a. Advance collective understandings of the impacts, resource needs, and recovery strategies of the participating stakeholder groups;
    b. Increase the effectiveness and shared ownership of disaster impact reduction efforts; and consequently,
    c. Increase community resilience to future hazard events.

4.2.1 Franz Josef case-study

Franz Josef/Waiau is a remote community located in Westland district, within the West Coast region of the South Island of New Zealand (Figure 39). The town is famous for the nearby temperate maritime glacier, which descends from the Southern Alps to around 400 metres above sea level. Kā Roimata o Hine Hukatere, later also named Franz Josef Glacier, was first shown to Europeans by Māori in the mid-19th Century (Glacier Country Tourism Group, 2018b). A settlement has existed for the purpose of showing the glacier to tourists since the late-19th Century, when tracks and bridges were built to provide access onto the glacier (Glacier Country Tourism Group, 2018b; Langridge et al., 2016). This settlement was later named after the glacier.

Franz Josef’s visitor numbers have risen sharply over the last decade, driven largely by a desire to see the glacier (Mitchell & Williams, 2018; Wilson et al., 2014). Franz Josef Glacier and the neighbouring Fox Glacier had 700,000 visitors in 2016, roughly 20% of total visitor arrivals in New Zealand in the same year (Tonkin + Taylor & EY, 2017). For context, in 2016, international tourism expenditure contributed NZ$14.5 billion or 20.7% of New Zealand’s total exports of goods and services (Stats NZ, 2016). This increase in visitors means that the number of tourists can dwarf the number of town residents during the summer peak tourist season. For example, in 2018, approximately 6,000 people per day walked the Franz Josef Glacier track at this time of year (Morton, 2018). The town, however, has a resident population of approximately 450 people (Stats NZ, 2013).

Community members have identified that they need business expansion, including larger premises, to cope with the current tourism “boom”, increased tourism in winter to improve sustainability, and business diversification to reduce the town’s dependence on the glacier, which is experiencing prolonged retreat (Purdie et al., 2014), for the town to continue to prosper. However, while the community wants to increase investment in Franz Josef and expand the town, development is presently constrained by the recognition that the town is exposed to natural hazards including earthquakes, floods, landslides, landslide-dambreak floods, severe storms (including ex-cyclones) and tornadoes (Westland District Council, 2002) (Figure 39).

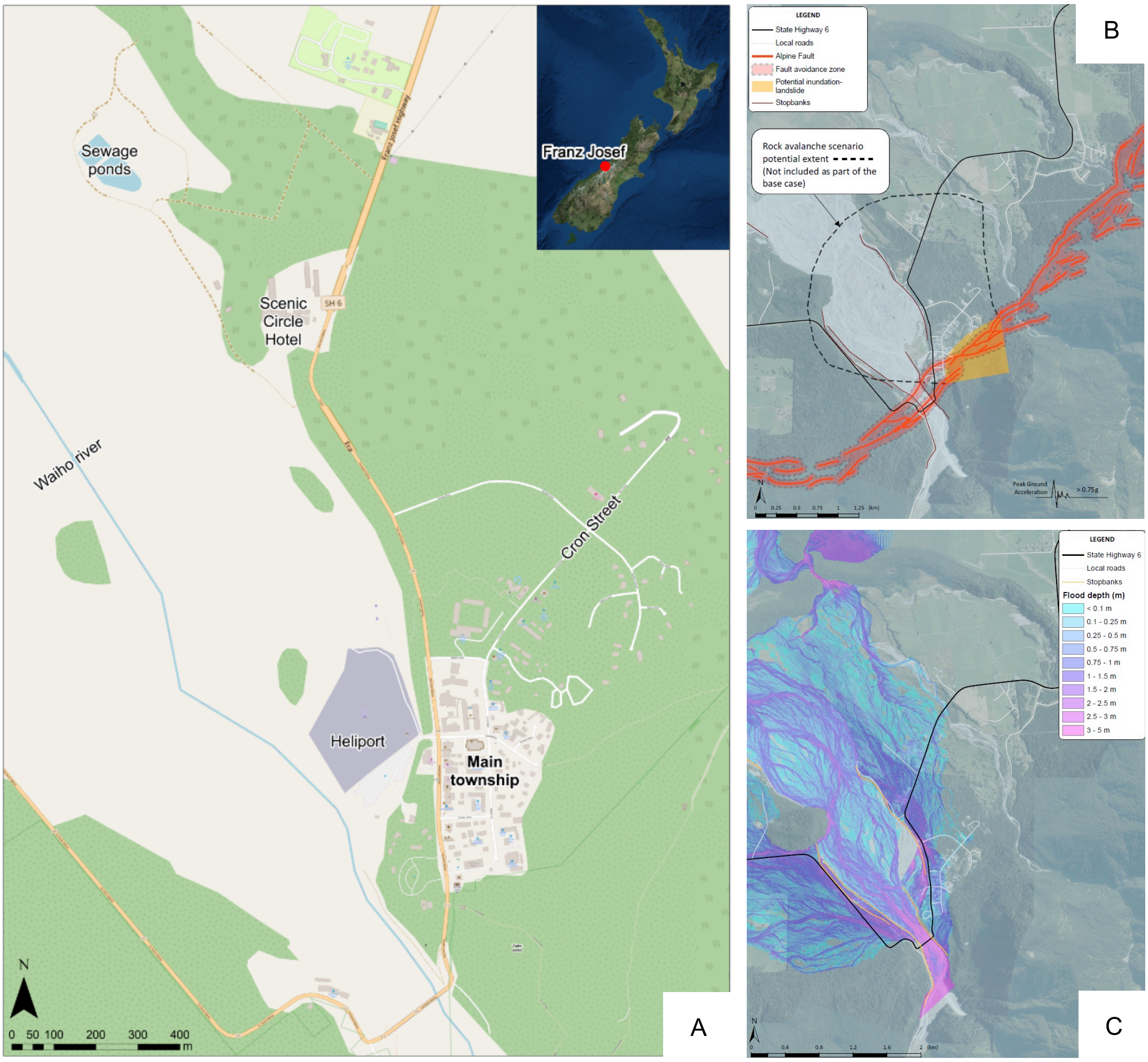

Figure 39. Maps of Franz Josef. A: Franz Josef, and its location within New Zealand. B: Alpine Fault trace, FRAZ, rockfall & landslide zones (Tonkin + Taylor & EY, 2017, p. 26). C: 100-year modelled river flood with 6 m bed aggradation (Tonkin + Taylor & EY, 2017, p. 29).

Franz Josef has developed at the foot of the Southern Alps, on the northern bank of the Waiho (Waiau) River, around and across what was later recognised to be the fault trace of the Alpine Fault (Langridge & Beban, 2011; Langridge & Ries, 2009; McSaveney & Davies, 1998; Wellman, 1953). This has meant that some buildings and town infrastructure are located directly on the fault trace (Figure 39). The Alpine Fault is active and considered capable of generating a M_w 8 earthquake (Stirling et al., 2012). Late in its current seismic cycle, this fault has an estimated ~30% probability of a major rupture in the next 50 years (Barnes et al., 2013; Cochran et al., 2017; De Pascale & Langridge, 2012; Stirling et al., 2012). The Waiho River also poses a constant flooding hazard. Major aggradation since the late-19th Century (Glacier Country Tourism Group, 2018a) has meant that the majority of the town is now located below the river bed. This makes Franz Josef completely reliant on stopbanks (river levees) for flood protection, which continue to considerably exacerbate aggradation

(Langridge et al., 2016; McSaveney & Davies, 1998). Nearby development potential is also reduced due to the flooding hazards posed by several nearby secondary catchments (Docherty Creek, Tartare Stream, Stony Creek and Potters Creek), and the town's range-front location, which presents a landslide risk (Langridge et al., 2016). While this landslide risk presently requires intensive investigation, it is potentially devastating (Barth, 2013; Langridge et al., 2016).

The threat of a major Alpine Fault earthquake, which could isolate Franz Josef and the wider West Coast region, has received focussed attention in New Zealand in recent years (Orchiston et al., 2018; Robinson et al., 2015). The annual probability of a major Alpine Fault earthquake is high (30% chance of a M_w 8.0 rupture in the next 50 years) (Stirling et al., 2012; Cochran et al., 2017) and prior to the present study, the national, regional and local implications of an Alpine Fault earthquake scenario had been considered by academics, disaster managers, infrastructure providers, and community members (McSaveney & Davies, 1998; Orchiston et al., 2013; Orchiston et al., 2018; Robinson et al., 2014; Robinson et al., 2015). Notably, Alpine Fault scenarios have been used in two recent and high-profile national exercises. For Exercise Te Ripahapa, an Alpine Fault scenario was developed for a national emergency management exercise in 2013 (Robinson et al., 2014). Subsequently, beginning in 2016, *Project AF8* ran six regional and one national collaborative response planning workshops, based around a 7-day **Al**pine **F**ault magnitude **8** earthquake scenario (building on the scenario developed for Exercise Te Ripahapa). *Project AF8* aimed to integrate regional plans and national planning, and workshop participants included emergency managers, policymakers, lifeline utilities, and welfare representatives, amongst others (Orchiston et al., 2018).

4.2.1.1 Franz Josef risk governance

Franz Josef is under the jurisdiction of Westland District Council (WDC), West Coast Regional Council (WCRC) and the New Zealand Government. The Resource Management Act (1991) tasks Councils with developing rules, objectives and policies to mitigate the effects from natural hazards. Specifically, regional councils are usually responsible for (amongst other responsibilities) regional policy statements, land use planning to avoid natural hazards, and ensuring sufficient development capacity for residential and business land to meet expected long-term demands of the region. WCRC fulfils this obligation through the West Coast Regional Policy Statement (West Coast Regional Council, 2000). District councils are usually responsible for (amongst other responsibilities) the effects of land use and ensuring sufficient development capacity for residential and business land to meet expected long-term demands of the district. WDC fulfils this obligation through rolling updates to the Westland District Plan (Westland District Council, 2002). Councils must consult with their communities when they prepare or review plans or regional policy statements, or consider a change or variation, but consultation approaches vary (MfE, 2018). In an evaluation of land use and emergency management plans for natural hazards in New Zealand, Saunders et al. (2015) find that information on the nature and location of natural hazards needs to be more accessible to the public, and more councils should implement a risk-based approach that engages with communities to determine levels of risk. However, whilst best practice, these are not required by legislation.

A summary timeline of risk governance actions and issues in Franz Josef, with increasing resolution closer to the time of writing, is provided in Figure 40. A detailed timeline of participatory governance in Franz Josef between 2016 and 2018 is provided in Appendix D.

Mid-19th C	Franz Josef Glacier named.
Late-19th C	Franz Josef settlement established for tourists to see the glacier. Plane flown under Waiho river swing bridge.
1953	**Alpine Fault recognised by Wellman (1953).**
1991	**Ministry for the Environment (1991) Resource Management Act established, requires West Coast Regional and District policy statements.**
1998	McSaveney & Davies (1998) *Natural Hazard Assessment for the Township of Franz Josef Glacier and its Environs* published.
2000	**West Coast Regional Policy Statement published (West Coast Regional Council, 2000). Identifies need to mitigate Alpine Fault risk.**
2002	**Westland District Plan publishes (Westland District Council, 2002). Identifies need to mitigate Alpine Fault risk.**
2009	Langridge & Ries (2009) map Alpine Fault and stipulate fault rupture avoidance zonation for WCRC.
2010 - 2011	Canterbury Earthquake Sequence.
2011	Langridge & Beban (2011) provide further advice for regarding active fault avoidance and planning measures for Franz Josef, including Fault Rupture Avoidance Zone (FRAZ).
2012	**Westland District Council propose Plan Change 7, including FRAZ in Franz Josef.**
Feb 2015	Langridge & Ries (2009) and Langridge & Beban (2011) GNS reports presented to Franz Josef community.
May 2015	**Franz Josef community members & University academics' begin collaborative workshops.**
May 2015	**Westland District Council approve Plan Change 7 after an independent commission.**
Jul 2015	Two separate Plan Change 7 appeals lodged to the Environment Court.
Aug 2015	**Franz Josef community members and local government policymakers' Working Group founded.**
Oct 2015	**Through Environment Court legal proceedings, the implementation of Plan Change 7 is postponed.**
Mar 2016	Waiho river flood.
Aug 2016	Langridge et al. (2016) *Natural Hazard Assessment for the Township of Franz Josef, Westland District* GNS Science hazardscape published.
Nov 2016	"Kaikōura" earthquake.
Dec 2016	**Westland District Council revokes Plan Change 7.**
Mar 2017	Franz Josef community members & local government policymakers' Working Group beings *Franz Josef Township: Natural Hazards Options Assessment and Cost Benefit Analysis.*
Oct 2017	*Franz Josef Township: Natural Hazards Options Assessment and Cost Benefit Analysis* published.
Feb 2018	Ex-cyclone Fehi and ex-cyclone Gita events.
Apr 2018	Franz Josef Feedback Summary on *Natural Hazards Options Assessment and Cost Benefit Analysis* published.

Figure 40. Franz Josef natural hazard risk governance summary timeline.

Management of Franz Josef's natural hazard risks has been highly contentious in the town (Day, 2003; Gough, 2001; Gough et al., 2001). Effective disaster impact reduction is challenging in Franz Josef due to its complex hazardscape, alongside its specific social, economic, cultural, and political context and history (Fischer, 2000; Gough, 2000; Gough et al., 2001; Remling & Veitayaki, 2016). This already complicated situation has been compounded by previous disaster impact reduction attempts that have eroded trust between community members, emergency managers, and government (Day, 2003; Gough 2001). The most notable recent example occurred in 2012, when WDC responded to recommendations by Langridge and Ries (2009) and Langridge and Beban (2011) with a proposal to update the Westland District Plan with Plan Change 7 (Westland District Council, 2012). Plan Change 7 introduced a "General Fault Rupture Avoidance Zone" along the

Alpine Fault trace throughout Westland, as well as stipulating a specific Fault Rupture Avoidance Zone (FRAZ) through the centre of Franz Josef (Westland District Council, 2012). Following the advice of an independent commission, this proposal was approved by WDC in May 2015 (Westland District Council, 2016). Franz Josef community members were concerned that the introduction of this avoidance zone would devalue properties and prevent further development within the FRAZ without providing a mechanism for the buildings and infrastructure within the FRAZ to relocate. Two separate appeals were lodged to the Environment Court against Plan Change 7 in July 2015 (Westland District Council, 2016). Despite an August 2015 Environment Court hearing of the appeals, and formal mediation between WDC and the appellants, no resolution had been reached by September 2015. Subsequently, the Environment Court postponed the implementation of Plan Change 7 for twelve months. Parties were required to agree to a resolution by February 2017 (after extensions were granted) or proceed to Environment Court (Westland District Council, 2016). In December 2016, appellants were invited to and attended a WDC meeting, to agree on a resolution. In this meeting, WDC resolved to remove Plan Change 7 (Westland District Council, 2017).

Despite this sequence of events, Franz Josef community members have continued to demonstrate a keen desire to participate in disaster impact reduction efforts. In 2015, Franz Josef's business collective, Franz Inc., invited academics from the University of Canterbury and the University of Auckland to assist them to develop a planning strategy to increase the resilience of the town. Scenario exercise workshops were established as the preferred collaborative methodology and the collaboration grew as Franz Inc. invited members of the wider Franz Josef community to participate.

Subsequently, a complex participatory disaster impact reduction process has developed, involving a wide range of stakeholders (Appendix E). This includes the above collaboration (funded by the NZ Government consortia research initiative *National Science Challenge* project *Resilience to Nature's Challenges*; Table 5), alongside the emergence of a distinct process led by district and regional councils alongside. WDC, which had been attending the Franz Inc. planning workshops, recognised that the many of the Council's "future planning" aims aligned with the work underway in the workshops. The community members were asked if they would like to align the work. A public meeting was held in August 2015, and the formation of the Franz Josef/Waiau Future Planning Working Group was agreed, consisting of WDC and WCRC elected members, representatives from Te Runanga o Makaawhio and DoC, the Community Development Officer, and eight community-elected representatives. The Working Group developed a broad list of projects to improve Franz Josef, and initially focussed on local infrastructure and streetscape issues (Westland District Council, 2016). In late 2015, WCRC also applied for funding from MBIE and commissioned GNS Science to create a Natural Hazard Assessment for the Township of Franz Josef, Westland District (Langridge et al., 2016). This assessment recommended that a risk management strategy should be developed for Franz Josef, including a thorough analysis of the potential resilience options. In May 2016, the Working Group agreed to check the assessment's recommendations against the WCRC Regional Growth Strategy, and an application would be prepared for Government funding for the resilience options analysis. The Government's Regional Growth Programme, with involvement from MBIE, MfE, DoC, MCDEM and NZ Transport Agency, granted funding to WCRC for the Franz Josef Township: Natural Hazards Options Assessment and Cost Benefit Analysis (Options Assessment), which was published in October 2017 (Tonkin + Taylor & EY, 2017).

After the Working Group was formed, the community remained committed to the collaboration between community members and academics. Notably, the Working Group collaborative process largely focussed on the direct impacts of flooding and earthquakes (Langridge et al., 2016; Tonkin + Taylor & EY, 2017), while a further established aim of the collaboration between community members and academics was to address disaster recovery planning. The approach detailed in this paper was designed to address this aim.

4.2.1.2 New Zealand infrastructure resilience

Franz Josef's dependence on the West Coast region's linear distributed infrastructure for service delivery also increases the town's vulnerability (Chapter 2; Appendix A). The West Coast region has no network redundancy (except in towns) for over 400 kilometres, meaning Franz Josef is only accessible via ground transportation by a single road (State Highway 6) and is serviced by only one powerline and one telecommunications line (Figure 41) (National Infrastructure Unit, 2015; Tonkin + Taylor & EY, 2017; Willis, 2014).

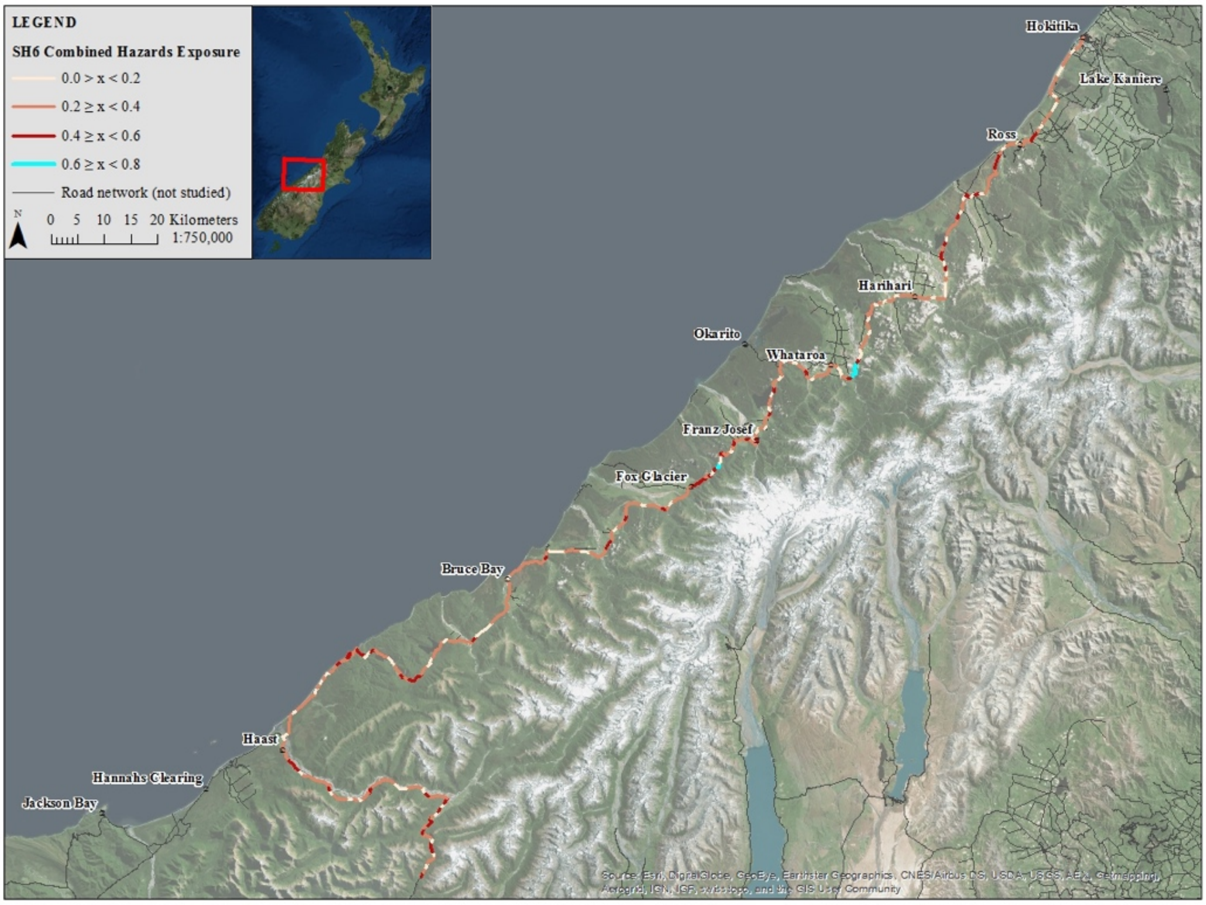

Figure 41. A map showing the South Island road network of New Zealand and the combined exposure of SH6 to earthquake rupture, landslide, debris flow and river flood (Appendix A, Figure 56).

With no redundancy, any disruption to any part of the distributed infrastructure networks can result in the partial and sometimes complete loss of a given community's essential services for considerable periods of time. Depending on the duration of the outage and various contextual factors, this can lead to potentially substantial social and economic impacts. The combination of low (or no) infrastructure redundancy and high hazard exposure (including earthquakes, landslides, landslide dam-break flooding, river flooding, rockfalls, severe storms, tornadoes and tsunami) in the West Coast region compounds the vulnerability of remote West Coast communities, including Franz Josef (Appendix A), and means that community members will likely be isolated in the event of a major disaster in the West Coast region. It has been identified by previous studies and the West Coast Civil Defence & Emergency Management (CDEM) Group that, when isolated, community members will likely be responsible for the immediate response efforts. This will include caring for stranded tourists, who vastly outnumber residents during peak tourist season, and are unlikely to be prepared for a disaster (Orchiston, 2013; West Coast CDEM Group, 2016).

Under the *Civil Defence Emergency Management Act 2002*, New Zealand government agencies at local, regional and national levels, infrastructure providers (often termed "lifeline utilities" or "lifelines") and emergency services all have defined functions and responsibilities for disaster readiness, reduction, response, and recovery. Table 5 summarises the roles and responsibilities of key organisations for this case-study. Section 60 requires every lifeline utility to be 'able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency' (CDEM Act 2002, p. 40). Lifeline utilities must also establish planning and operational relationships with their regional Civil Defence & Emergency Management (CDEM) Group under the Act. In most regions, lifeline utilities predominantly fulfil their duties under the act by participating in regional lifelines groups, with national representation and coordination undertaken by the New Zealand Lifelines Council (est. 1999). In the West Coast region, this collaboration is enabled through the West Coast Engineering Lifelines Group, which is led by the West Coast Civil Defence & Emergency Management (CDEM) Group and includes representatives from the West Coast Regional Council, Buller, Grey and Westland District Councils, and infrastructure providers, including: Aratuna Freighters, Buller Electricity, Chorus, Downer, Elgas, Fulton Hogan, Hokitika Airport Authority, KiwiRail, the Ministry of Civil Defence & Emergency Management (MCDEM), NZ Transport Agency, Opus, Port of Greymouth, Rockgas, Solid Energy, Spark, Transport Logistics Ltd., Transpower, Trustpower, Westland Milk Products, Vodafone, Westport Airport, Westport Harbour, and Westpower (key roles and responsibilities are summarised in Table 5). Prior to this project, the participating academics had built a deep, trusting relationship with the West Coast Engineering Lifelines Group, in part by regularly attending Lifelines Group meetings since 2015, as part of a long-term researcher collaboration under the New Zealand *Resilience to Nature's Challenges* research programme.

The West Coast Engineering Lifelines Group (Table 5) has undertaken a number of projects including natural hazards scenario planning and post-event debriefs to assess and improve the resilience of West Coast lifelines (e.g. McCahon et al., 2006, 2017; West Coast Regional Council, 2014). These projects and other work fostered or contributed to by the West Coast Engineering Lifelines Group and its members have developed valuable inter-personal and inter-corporate relationships and have improved the infrastructure resilience of the West Coast region. However, up to the point of the activity described in this paper, community members had not been given the opportunity to participate in these planning and decision-making processes.

The remote character of Franz Josef and the town's dependence on distributed infrastructure means that there is an additional need for community participation, as community members in remote locations are relied upon to implement disaster resilience for cost efficiency (Remling & Veitayaki, 2016) and when isolated, community members lead immediate response efforts in the absence of input from authorities (Gardner, 2015; Orchiston, 2013) (Section 4.2). Therefore, this project aimed to provide a platform to increase disaster resilience by bringing Franz Josef community members together with West Coast region distributed infrastructure providers, emergency managers, local government decisionmakers and University academics.

Table 5. A table summarising key risk governance organisations and their relevant roles and responsibilities in respect to this case-study in Franz Josef, New Zealand.

Organisation	**Roles and responsibilities**
GNS Science	A New Zealand Crown Research Institute, focussed on geology, geophysics (including seismology and volcanology) and nuclear science. GNS Science researches, monitors and provides advice on natural hazard risks and impacts.
Civil Defence & Emergency Management (CDEM) Group	New Zealand has 16 regional CDEM Groups, which lead regional hazard risk reduction, preparedness, response and recovery. CDEM Groups operate under the CDEM Act 2002 and National CDEM Plan, and also make commitments beyond these responsibilities to reduce the impacts of emergencies. Franz Josef sits within the West Coast CDEM Group.
Ministry of Civil Defence & Emergency Management (MCDEM)	Leads national hazard risk reduction, preparedness, response and recovery policy, and supports the management of CDEM Groups, upholding the CDEM Act 2002.
Ministry for the Environment	Upholds the Resource Management Act 1991, which tasks Councils to develop rules, objectives and policies to mitigate the effects from natural hazards.
NZ Transport Agency	An independent crown entity, responsible (amongst other roles) for the State Highway network and for allocating funds from the National Land Transport Fund to land transport activities, including local roads, state highways and public transport and, together with local and regional government, for funding local roads and public transport infrastructure and services. As a lifeline utility, NZ Transport Agency must be 'able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency' under Section 60 of the CDEM Act 2002 Lifeline utilities must also establish planning and operational relationships with their regional Civil Defence & Emergency Management (CDEM) Group under the Act. NZ Transport Agency fulfils this obligation by participating in regional lifelines groups, including the West Coast Engineering Lifelines Group.
Project AF8	A three-year programme of scientific modelling, response planning and community engagement, led by South Island CDEM Groups.
Resilience to Nature's Challenge's	A New Zealand Government Ministry of Business, Innovation and Employment (MBIE) funded "National Science Challenge". A cross-research institutes collaboration, focussed on research that supports increasing resilience to natural hazard disasters.

West Coast Engineering Lifelines Group	Critical infrastructure providers must establish planning and operational relationships with their regional CDEM Group, under the CDEM Act 2002. In the West Coast region, these lifeline utilities predominantly fulfil their duties by participating in the West Coast Engineering Lifelines Group. This group is led by the West Coast Civil Defence & Emergency Management (CDEM) Group and includes representatives from the West Coast Regional Council, Buller, Grey and Westland District Councils, and infrastructure providers, including: Aratuna Freighters, Buller Electricity, Chorus, Downer, Elgas, Fulton Hogan, Hokitika Airport Authority, KiwiRail, the Ministry of Civil Defence & Emergency Management (MCDEM), NZ Transport Agency, Opus, Port of Greymouth, Rockgas, Solid Energy, Spark, Transport Logistics Ltd., Transpower, Trustpower, Westland Milk Products, Vodafone, Westport Airport, Westport Harbour, and Westpower.
West Coast Regional Council	The regional council responsible for the West Coast region of New Zealand. The Council must develop rules, objectives and policies to mitigate the effects from natural hazards under the Resource Management Act 1991. Specifically, regional councils are usually responsible for (amongst other responsibilities) regional policy statements, land use to avoid natural hazards, and ensuring sufficient development capacity for residential and business land to meet expected long-term demands of the region.
Westland District Council	The district council responsible for Westland District, within the West Coast Region of New Zealand. The Council must develop rules, objectives and policies to mitigate the effects from natural hazards under the Resource Management Act 1991. Specifically, district councils are usually responsible for (amongst other responsibilities) the effects of land use and ensuring sufficient development capacity for residential and business land to meet expected long-term demands of the district.
Westpower	Electricity distributor responsible for distribution and local generation of electricity for the majority of the West Coast region, including Franz Josef. As a lifeline utility, Westpower must be ‘able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency’ under Section 60 of the CDEM Act 2002 Lifeline utilities must also establish planning and operational relationships with their regional Civil Defence & Emergency Management (CDEM) Group under the Act. Westpower fulfils this obligation by participating in the West Coast Engineering Lifelines Group.

4.3 Literature review: participatory approaches for disaster impact reduction

The development of effective participatory approaches that bring community members together with decision makers and give them power to influence decision-making has lagged behind increasing recognition of their importance (Ackerman, 2004; Díez et al., 2015; Howard, 2018; Section 1 herein). Resilience is usually considered probabilistically. For a given hazard, probabilistic analysis aims to quantify the likelihood of all possible events and their consequent impacts at a given location. A good example is Probabilistic Seismic Hazard Analysis (PSHA; Baker, 2008), which details the expected peak ground acceleration (PGA) with various exceedance probabilities over timescales of hundreds to thousands of years (e.g. Stirling et al., 2012). Probabilistic analysis is used to identify the most likely hazards over a long time period, and so is especially useful for informing engineering design codes and for insurance. In contrast, a deterministic analysis considers one possible event and its impacts; deterministic scenarios do not consider the full range of possible outcomes, and do not quantify the likelihood these outcomes. Deterministic scenarios are widely used for emergency management exercises, personnel training, risk communication and contingency planning. Among these applications, using disaster event scenarios as boundary objects has been proven to enable collaboration between government, practitioners and hazard risk and impacts experts to reduce disaster impacts (Alexander, 2000; Orchiston et al., 2018; Perry et al., 2011; Robinson, 2014). The sociological concept of a "boundary object" was introduced by Star and Griesemer (1989, p. 393) to refer to 'objects which both inhabit several intersecting social worlds *and* satisfy the informational requirements of each of them', who also describe them as 'a means of translation'. Using disaster event scenarios has been proven to enable cross-sector collaboration (Cash et al., 2003; Thompson et al., 2015), when all stakeholder groups perceive the boundary object to be: i) *credible* by being accurate (e.g. scientifically, technically, locally); ii) *legitimate* by fairly reflecting stakeholders' divergent views and interests; and iii) *relevant* to stakeholder needs (Beaven et al., 2016; Cash et al., 2003). When considering large disaster events, this means that the scenario must be relevant at local, regional and national scales, and must encompass all pre-, syn-, and post-event implications (Cutter, 1996). It has been established that disaster event scenarios enable practitioners, policymakers and researchers to co-create integrated disaster resilience knowledge (Alexander, 2000; Centre for Advanced Engineering, 1997; Orchiston et al., 2018; Perry et al., 2011; Robinson, 2014).

While both probabilistic and deterministic approaches are clearly important for resilience, probabilistic approaches are more suited to a longer-term view based primarily around insurance, land-use planning, financial security and life safety, whereas deterministic scenarios are more suitable for collaborative planning. However, there is notable overlap between the two approaches: probabilistic modelling is often used to help generate a hazard scenario, providing scientific credibility to the deterministic approach (e.g. Orchiston et al., 2018; Centre for Advanced Engineering, 1997).

It is logical that integrating community members with and alongside practitioners, policymakers and researchers will offer even greater advantages to those found for government, practitioners, and hazard risk and impacts experts (Davies et al., 2015). Therefore, we now review scenario-based participatory approaches to date.

4.3.1 Scenarios

The scenario literature has developed across disciplines including military (DeWeerd, 1967; Kahn & Wiener, 1967), corporate (Shell International, 2003; Wack, 1985a; Wack, 1985b), environmental (Butler et al., 2016; Kishita et al., 2016; Wodak & Neale, 2015), and emergency management studies (Alexander, 1999; Alexander, 2000). As discussed above, the success of many scenario-based participatory approaches lies in their ability to be used as boundary objects to enable collaboration between stakeholders. For the scenario to be relevant, credible and legitimate for all participating stakeholder groups (Cash et al., 2003), the scenario-based participatory approach must be context-specific, which has led to an abundance of scenario-based participatory approaches.

Recently, scenarios have become increasingly prevalent through high-profile, multi-disciplinary, often international and multi-year projects concerning environmental challenges, including the Brundtland Report (Keeble, 1988), the Intergovernmental Panel on Climate Change (Nakicenovic et al., 2000), and the United Nations Millennium Ecosystem Assessment (Millennium Assessment Board, 2005). These projects have established principles which are common to scenario-based approaches for environmental challenges, including natural hazards (Butler et al., 2016; Jenkins, 2000; Kishita et al., 2016; Wodak & Neale, 2015), which include:

1) combining qualitative descriptions and quantitative simulations, enabling collaboration across knowledge fields with a scientific underpinning;
2) typically using one of three scenario types:
    i. Forecasting: scenario planning which begins in the present and details futures based around changing inputs;
    ii. Backcasting: scenario planning in which a future is detailed and so is driven by an interest in the conditions required to get to this predetermined future;
    iii. Event: scenario planning which details the consequence of a specified future event;
3) often involving stakeholder participation.

The present paper details a scenario-based participatory approach to reduce impacts from disasters triggered by natural hazards, such as floods, earthquakes, tsunami, and volcanic eruptions. Beyond the general principles for scenario-based approaches for environmental challenges outlined above, this approach also builds on principles from the broader scenario literature. Therefore, we now briefly summarise key outcomes from the scenario literature which are applicable to the methodology presented in Section 4.4.

4.3.2 Definitions

The abundance of applications for scenarios has led to numerous definitions of the term. However, a “scenario” can be broadly defined as a credible (but necessarily simplified) storyline which allows discursive exploration of future possibilities. Scenarios must be plausible, internally consistent and coherent (Bishop et al., 2007; Butler et al., 2016; Duinker & Greig, 2007; Kishita et al., 2016, p. 334; Oteros-Rozas et al., 2015; Wodak & Neale, 2015). While the definition of the term "scenario" is broadly agreed, there is more confusion when the term is used in conjunction with other terms (Wodak & Neale, 2015). A common confusion is equating scenario planning with scenario development (Bishop et al., 2007). Bishop et al. (2007) define scenario planning as a 'complete foresight study', and scenario development as 'specifically… creating actual stories about the future'. In this way, scenario development can be viewed as one aspect or technique of the overarching methodology of scenario planning (Bishop et al., 2007).

Herein we use "scenario-based participatory approach" as a substitute for "scenario planning", given our focus on participation and to avoid confusion between disciplines, while recognising that it is not applicable to all applications of scenarios. We also define a "stakeholder" as a person who will be affected by the outcomes of the participatory process, and a "stakeholder group" is defined as a community or organisation affected by the outcomes of the participatory process. Finally, we define a "community" as a varied group of people who are exposed to the same disaster impacts through social, spatial and/or economic links (Davies et al., 2015; Gaillard & Mercer, 2013).

4.3.3 Knowledge integration

Although community members often participate in scenario-based participatory approaches for disaster impact reduction (DPMC, 2016; Hagendijk & Irwin, 2006; Jones & Benthien, 2011; Reed et al., 2013), as summarised in Section 4.2, there is a lack of documented evidence of scenario-based participatory processes that integrate and balance the knowledge of community members with and alongside that of practitioners, policymakers and researchers (Reed et al., 2013). For example, Broad et al. (2007) observed a process where participants chose between scenarios, but the range of scenarios was narrow and already developed by a risk-averse government agency, which retained the right to overturn any decision made by the participants (Reed et al., 2013). As already discussed, such unbalanced participation reduces opportunities for knowledge integration. Whilst other stakeholders can attempt to ensure that the scenario is relevant to community members (Remling & Veitayaki, 2016), only community members understand what is relevant to them. Other stakeholders lack the local knowledge, including the implications of livelihood, habitability and wellbeing impacts, held by community members (Centre for Advanced Engineering, 1997; Gaillard & Mercer, 2013). Moreover, such unbalanced participation can also reinforce existing privileges (Cooke & Kothari, 2001; Nelson & Wright, 1995), reduce trust (which must be earned) in the process and/or facilitator (Eiser et al., 2012; Ravera et al., 2011; Reed, 2008), and cause engagement fatigue and disillusionment (Burton et al., 2004; Cooke, 2004; Reed, 2008; Wondolleck & Yaffee, 2000), all of which discourage (future) participation.

Nevertheless, scenario-based participatory approaches (which have not included community members) have demonstrated three key advantages in collaborations between government, practitioners, and hazard and impacts experts for disaster impact reduction, which we summarise and detail below:

1) practitioners and policymakers have technical and local knowledge which can be used to validate and co-produce impacts scenarios;
2) involving policymakers and organisations in scenario planning can help to ensure that pre-disaster resilience measures, which can be of considerable value, are implemented.

The predictive ability of disaster event scenarios has also made them a popular approach for disaster impact reduction, particularly for earthquakes, which cannot be predicted to any extent (Alexander, 2000; Fenwick, 2012; Preuss & Godfrey, 2006; Robinson et al., 2014). Accordingly,

3a) scenario planning can establish relationships which allow modification of response planning, which is vital when disasters (which are, by definition, unexpected; Davies, 2015) happen; and

3b) sustaining these relationships is vital to ensuring the success of disaster response at any time in the future, and can have the added benefit of continuing to improve and implement resilience measures before the next disaster.

Using scenarios to bring research, government, and private sector stakeholders together has demonstrated further advantages. First, it allows technical, official and local knowledge to be integrated with academic knowledge through validation of, or co-production of, the scenario, which improves the scenario credibility and relevance. The integrated knowledge can challenge prevailing assumptions and identify new risks, vulnerabilities, and resilience solutions (Davies et al., 2015; de Andrade & Szlafsztein, 2015; Ellemor, 2005; Manuel-Navarrete et al., 2011; Murphy et al., 2014). For example, infrastructure providers typically have the best understanding of their infrastructure system, and of likely service outage and restoration times for their networks, given a specific event (e.g. Deligne et al., 2015).

Second, involving practitioners and policymakers in scenario planning can help to ensure the scenario is relevant to them (Davies et al., 2015; Pearce, 2003; Remling & Veitayaki, 2016). This encourages successful implementation of resilience measures. For example, the New Zealand "Risks and Realities" project (Centre for Advanced Engineering, 1997), was an intensive workshop held by Christchurch Engineering Lifelines. Workshop participants included infrastructure providers, emergency managers and policymakers, and University academics, including engineers, seismologists and hazard scientists. The workshop enabled direct collaboration between all stakeholder groups involved. This project identified natural hazards vulnerabilities using seven scenarios, including flood, seismic, wind, tsunami, and snow. Having invested in the scenario work, the infrastructure companies then successfully implemented resilience measures. For example, the region's electricity distributor commenced a seismic strengthening programme in 1996 (the Risks and Realities project report was published in 1997, but the project triggered this programme of work). After the 2010/2011 Canterbury Earthquake Sequence, it was estimated that this $6 million resilience investment saved $60 to $65 million in direct asset replacement costs and repairs alone (Fenwick, 2012).

Third, formation of inter-personal and inter-corporate relationships has consistently been found to be among the most valuable outcomes of planning processes. For example, the city of Los Angeles, USA, prepared a recovery and reconstruction plan before the 1994 Northridge earthquake. Although this plan was hardly referred to during the earthquake, staff performed most of the actions they were assigned in the plan (Spangle Associates & Robert Olson Associates, 1997). The value of the plan lay in the planning process, wherein contacts were made and tasks agreed upon (Becker et al., 2008). There was similar evidence during the Canterbury Earthquake Sequence, where a review found that 'the inter-corporate and inter-personal relationships developed as *Risks and Realities* was prepared proved most valuable during earthquake responses' (Fenwick, 2012, p. iii). Subsequently sustaining these relationships has been found to be vital to the success of natural hazards scenario planning. For example, a review of the impact of the 2010/2011 Canterbury Earthquake Sequence found 'the damage would have been greater and the response slower if the steps recommended in Risks and Realities *and other preparatory work fostered by the Group* had not been taken (Fenwick, 2012, p. ii, emphasis added). Therefore, (pre-event) resilience measures were not only implemented as a direct result of the scenario planning, but also because of sustained relationships, through which further (post-event) resilience measures were identified. On the other hand, Hurricane Katrina provides an example of the negative implications of not sustaining relationships. In 2004, "Hurricane Pam" scenario planning simulated a slow-moving category 3 hurricane causing a storm surge which topped the levees in New Orleans, USA. The following year, Hurricane Katrina caused 1,200 deaths and $108 billion of property damage (Blake et al., 2011) in a very similar event, and showed that the "Hurricane Pam" exercise was prescient. The failings during Hurricane Katrina in 2005 were later partially attributed to a lack of continued collaboration (see Robinson et al., 2014 for a summary).

4.4 Methodology

To integrate and balance the knowledge of community members with and alongside that of practitioners, policymakers and researchers for disaster impact reduction efforts, our approach sequences participation methodologies using a hazard event scenario as a boundary object. In this section, we first detail methodology development, based on a review of scenario and participation literatures, before outlining the method. We then describe how this method was applied in a "pre-disaster" collaboration between community members, infrastructure providers, emergency managers, local government policymakers and researchers, to proactively increase the resilience of Franz Josef, New Zealand, to future disaster events.

4.4.1 Method development

4.4.1.1 Developing the scenario

4.4.1.1.1 Number of scenarios

While scenario planning offers advantages, using such a deterministic approach instead of a probabilistic approach inevitably means that not all possibilities will be considered. This can lead to an incomplete and potentially skewed perception of risk amongst stakeholders. To counteract this limitation, many environmental scenario exercises use multiple scenarios, allowing a wider range of distinct plausible futures to be explored (Centre for Advanced Engineering, 1997; Ratcliffe, 2000; Robinson et al., 2018; Wodak & Neale, 2015). However, even using many scenarios, not all possibilities will be considered, and greater scenario numbers lead to complexity that can reduce process engagement, and, as already discussed, stakeholder fatigue and disillusion if substantial effort is required from stakeholders with little immediate tangible benefit (Chang et al., 2014; Duinker & Greig, 2007; Thompson et al., 2015; Wodak & Neale, 2015).

Following a synthesis of scenario exercises, Wodak and Neale (2015) find that using either two or four scenarios is a consistent compromise throughout the literature. These numbers allow sufficient exploration of futures whilst keeping complexity (which can reduce process engagement) low, as well as preventing participants from mistakenly treating the middle or only scenario as the “most likely” (Wodak & Neale, 2015).

However, it is common to use only one scenario (e.g. Deligne et al., 2015; Jones & Benthien, 2011; McDaniels et al., 2015; Orchiston et al., 2013; Orchiston et al., 2018; Robinson et al., 2014). Notably, this aligns with the need to manage engagement expectations (using more scenarios inherently requires more engagement), which remains the most important consideration (Wodak & Neale, 2015). Moreover, “single” scenarios often form part of a larger objective, such as annual national emergency management exercise programmes (e.g. DPMC, 2016; FEMA, 2018; GOV.UK, 2014). This is likely to reduce the tendency to prepare only for the “single” (“most likely”) scenario.

4.4.1.1.2 Developing the hazard scenario

Discussion of how to select scenarios is limited within the literature. However, this question is important because it may influence the effectiveness of the scenario-based participatory approach. If all stakeholders choose the scenario, then provided that knowledge integration is well-balanced between stakeholders, it should help ensure that the scenario is relevant to them (Kishita et al., 2016; Kok et al., 2007; Reed et al., 2013; Swart et al., 2004; Walz et al., 2007). Regardless of who chooses the scenario, hazard scenarios are predominantly developed by hazard experts, who usually have the best understanding of the nature and range of severity of hazards, and so also have a strong role in guiding the overall scenario selection. Natural hazards scenario development can be subdivided to provide a distinction between hazard and impact scenarios (also referred to as event and effects scenarios, respectively) (Robinson et al., 2014). The hazard scenario describes the physical nature of a specific natural hazard event. The impact scenario describes the effect of this scenario event on society. These different subjects mean that the impacts scenario is usually more collaboratively developed than the hazard scenario, involving policymakers, practitioners, and community members alongside hazard and also often impacts experts (Alexander, 2000; Davies et al., 2015; Robinson et al., 2014).

Alexander (2000) recommends that the scenario should be a “reference event”; an example of what is expected to happen based on a past hazard event applied to modern conditions. This contributes to ensuring the scenario is realistic. Notably, this also limits the scenario to recorded past events, although it is possible to transfer events which have occurred, for example, on similar earthquake faults, to reduce this limitation. Alexander (2000) also argues that scenarios should be hypothetical to avoid inadvertently restricting solutions to preconditioned outcomes, based on hindsight (Robinson et al., 2014).

Building on the work of Alexander (2000), Robinson et al. (2014, p. 19) outline that hazard scenarios must:

1. ‘Be scientifically realistic and consistent with current knowledge;
2. ‘Be of sufficient size to generate consequences applicable to the scale of the exercise [i.e. Robinson et al. (2014) needed to generate a scenario for all New Zealand South Island CDEM Groups, so needed to identify a hazard which would generate natural effects and subsequent impacts across the entire South Island];
3. ‘Be likely enough not to be dismissed as rare or extreme; and
4. ‘Consist of a single, specific outcome rather than probabilistic ranges.’

Robinson et al. (2014) also note that there is a need to ensure preparation for both more frequent, low impact events and less frequent, high impact events. Therefore, when selecting a scenario, consideration of the participants’ recent experiences with scenarios and real-world hazards is encouraged.

While useful and among the best available, the Alexander (2000) and Robinson et al. (2014) guidelines remain broad. For example, there is debate but little to no guidance in the literature as to whether an entirely catastrophic event may be too alarming or too large for a community to comprehend (Alexander, 2000; Wiggins, 1996). Often, “worst-case scenarios” are used. These describe the maximum credible event, meaning (theoretically) that by becoming resilient to the maximum event, communities automatically become resilient to any event of that hazard type (Davies, 2015). Davies et al. (2015) argue that a large part of the value of using a scenario approach is precisely to address low probability, high impact events. Probabilistic hazard analyses are normal in policy, and useful for governments assessing disaster risk over large areas. However, for community members aiming to increase resilience for a small area within a realistic planning timeframe, disasters are unlikely to match their probability of occurrence (Davies et al., 2015). Therefore, Davies et al. (2015) argue that scenarios offer the opportunity to ‘enable communities to plan for large, poorly-quantified or unexpected events that occur rarely (but will occur, and can occur at any time)'. However, recent disasters (for example, the 2011 Great East Japan Earthquake and Tsunami) have demonstrated that "maximum credible events" can be exceeded and so are misleading for resilience planning. Moreover, worst-case scenarios are, by definition, the least likely events (Davies, 2015). This may discourage their use, especially if resilience to that hazard is not judged by stakeholders to be a priority. More recently, Robinson et al. (2018) modelled 90 different earthquake scenarios to establish whether impacts are specific to certain hazards or occur irrespective of the hazard scenario. Robinson et al. (2018) find that similar impacts occur irrespective of the hazard event scenario and that these impacts are typically closed to the minimum than the worst case, suggesting that planning for worst-case scenarios may be an unnecessarily large burden on limited resources available for disaster impact reduction.

Scenario scaling is the practice of mapping issues and content from a pre-existing and potentially separate scenario onto a new, temporally, spatially, and/or topically different scenario (it does not refer to mathematical scaling of quantitative models or scenarios) (Wodak & Neale, 2015). Scaling is a common practice due to limited resources and time. However, scaling compounds problems around haphazard scenario selection, either due to whatever topic is trendy at the time, or simply because another scenario can be repurposed, rather than considering the need and purpose of the scenario in detail (Jenkins, 2000). Alcamo (2008) outlines four criteria to determine whether scaling is appropriate for the scenario:

1) purpose and potential users of the scenario (e.g. what spatial and temporal scales are the scenario participants interested in?);
2) factors and processes (e.g. what scale do the scenario processes operate at?);
3) actors/institutions (e.g. at which scale will the actors/institutions influence scenario developments?);
4) quantification/data availability (e.g. at which scale is data collectable or available?) (Wodak & Neale, 2015).

Again, there is a clear need for more documentation of scenario scaling in the literature to shape best practice, because although it is frequently utilised, there is little coverage at present (Wodak & Neale, 2015).

In summary, the literature lacks guidance on how stakeholders should develop hazard scenarios for scenario-based participatory approaches. This is an area in which greater documentation and further research would be valuable.

4.4.1.2 Participation in scenario-based planning

Overall, there is little guidance specific to scenario-based participatory approaches. When designing a participatory decision-making process, systematic identification and selection of stakeholders is first required to ensure that the process is not biased (Reed et al., 2013). In an analysis of methodological frameworks used to develop participatory scenario processes for environmental management, Reed et al. (2013, p. 360) find that 'the most important factors associated with success or failure were associated with process design and participant selection'. However, despite the critical importance of participant selection for successful participatory decision-making projects, this step is rarely taken (Reed et al., 2013). Stakeholder analysis is designed to successfully identify stakeholders for participation in a decision-making process. Reed et al. (2013, p. 348) describe stakeholder analysis as 'a process that: i) defines aspects of a social and/or natural system affected by a decision or action, ii) identifies individuals and groups who are affected by or can affect those parts of the system (this may include non-human and non-living entities and future generations); and iii) prioritises these individuals and groups for involvement in the decision-making process.' A wide variety of tools and approaches have been developed for stakeholder analysis, suitable to a range of contexts, so we do not detail these here. For a full review of stakeholder analysis methods, see Reed et al. (2009).

Like all participatory processes, scenario-based participatory approaches also require highly-skilled facilitation to be successful (Reed et al., 2013; Richards et al., 2004; Riddell et al., 2018). Reed (2008, p. 2425) argues that 'the outcome of any participatory process is far more sensitive to the manner in which it is conducted than the tools that are used' because 'different facilitators can use the same tools with radically different outcomes, depending on their skill level' and experience. Therefore, facilitation adds a complex component to scenario-based participatory approaches, above and beyond the design of the process. Notably, given its importance to all participatory exercises (Wodak & Neale, 2015), while good facilitation is possible, facilitation is clearly an area which requires more investment.

The participation literature describes characteristics of, or requirements to be, a successful facilitator. For example, successful facilitators must be perceived to be impartial, open to multiple perspectives, and approachable; capable of sustaining positive group dynamics, balancing strong opinions, and handling dominating or offensive individuals; and must encourage participants to question assumptions and re-evaluate entrenched positions, get the most out of reticent individuals, and facilitate the process to reach desired outcomes (Reed, 2008; Riddell et al., 2018). Accordingly, the literature suggests that the facilitator can come from any stakeholder group (or be independent), if they possess these characteristics. Techniques have also been developed to aid facilitation (e.g. Cooke, 2004; Tompkins et al., 2008). Reed (2008, p. 2425) summarises some of these, with examples including: 'the development of ground rules that groups agree to follow, meticulous planning, psychological approaches to deal with difficult individuals and group dynamics, and being familiar with a wide range of alternative tools that can be adapted to the circumstances'. However, Reed (2008, p. 2425) argues that these attributes are difficult to teach; they 'tend to be developed through years of experience, intuition and empathy'.

Within scenario-based exercises, Wodak and Neale (2015) find two dominant methods for facilitation within the literature:

1) the essentialist method, which requires the facilitator to control the topic of discussion as well as the tools used to facilitate this discussion; and

2) the social constructionist method, in which the facilitator mediates the group dynamic, and is less concerned with the "relevance" of the discussion.

These two methods both use a single facilitator, although the importance of including other non-participants is also recognised (Wodak & Neale, 2015). For example, scribes and timekeepers can aid facilitation (James et al., 2015; Wright & Cairns, 2011) and experts can advise on topics being discussed, without being participants (e.g. Alcamo, 2008).

4.4.2 Method: The AF8+ scenario-based participatory approach

A scenario-based participatory approach was designed as follows, based on the above review of scenario and participation literatures. Notably, this method was developed for a context where community members had invited academics to assist them to develop a planning strategy to increase the resilience of their town (Section 4.2.1.1). Also note that to address the needs identified in steps A and B, our method used a scenario-based participatory approach (steps C and D). Non-scenario based participatory approaches may be more suitable (following steps A and B) to address other needs.

A. Identify need:
Work with community members to establish their most pressing collective needs, based on the community's unique social, economic, cultural, and political context. Identify which need is going to be addressed through the process.

B. Design participation:
Select other stakeholder groups associated with the identified need (e.g. council, emergency managers, lifelines, scientists, business groups). Work with each stakeholder group to design a series of participation opportunities, discussing: types of participants, modes of recruitment, modes of communication, and the roles of participants (see Aoki, 2018).

C. Develop scenario:
In consultation with the participating stakeholder groups, decide on an appropriate scenario relevant to the identified need. Develop this scenario.

D. Co-create scenario:
The series of participation opportunities allows stakeholder groups to further develop the scenario in a sequence. Provide both the previously developed scenario and the co-created outputs from other stakeholder groups' participation as inputs for subsequent stakeholder groups' participation opportunities, so that additions to the scenario continually build on all previous outputs.

This approach was applied to address the disaster recovery planning goal within an established "pre-disaster" participatory disaster impact reduction collaboration between Franz Josef community members and University academics (Section 4.1). There were two phases of the project, each with a distinct methodology; the hazard scenario, and the participatory, iterative development of an integrated impacts scenario through a sequence of participatory workshops.

4.4.2.1 Developing the AF8+ hazard scenario

During consultation with the community, Franz Josef community members identified the need to plan for recovery from a disaster (Section 4.1). In response, academics identified the need to develop a low-probability, high-impact hazard event scenario which would have long-term, national-scale consequences. The participating academics, in collaboration with *Resilience to Nature's Challenges* researchers, achieved this by up-scaling the *Project AF8* **A**lpine **F**ault magnitude **8** scenario (Orchiston et al., 2016) from a 7-day to a 10-year "AF8+" scenario to create the "AF8+" hazard scenario. When up-scaling the *Project AF8* scenario, some hazard severities were reduced (e.g. removal of a 1-in-100 year rainstorm on Day 3 and large magnitude aftershocks and landslides in each CDEM region), as these were originally introduced to emphasise the emergency response focus (Orchiston et al., 2016; Zorn et al., 2018). A new, 10-year aftershock sequence was created by transferring the aftershock sequence from the 2002 M_w 7.9 earthquake on the Denali Fault, Alaska. The rainfall sequence was transferred from the previous ten years of South Island rainfall data. Finally, features of Exercise Te Ripahapa (Robinson et al., 2014) were also included. Debris flows were not included as hazard scenario components due to time constraints, but academics did discuss these with participants.

The AF8+ scenario detailed hazard magnitude and temporal and spatial extents and, by overlaying buildings and distributed infrastructure, exposure (Appendix F). These were detailed at spatial scales relevant to the participating stakeholder groups (e.g. local for community members, regional or national for an infrastructure provider). Exposure to earthquake rupture damage, earthquake shaking damage and rockfall damage was determined through best judgement by the *Resilience to Nature's Challenges* researchers (including the participating academics). The exposure to landslides was determined through the approach of Robinson et al. (2016). A co-seismic landslide hazard map at 60 m resolution was produced based on shaking intensity, slope angle, slope position, and distances to streams and faults. The best judgement of *Resilience to Nature's Challenges* researchers (including the participating academics) was then used to systematically determine the number and distribution of landslides, dependent upon likelihood scores. Landslide dams were also included using the best judgement of *Resilience to Nature's Challenges* researchers. Based upon experiences from the 2015 Nepal and 2016 "Kaikōura" earthquakes (Dellow et al., 2017; Roback et al., 2018), new landslides after the main shock were only inferred to occur during a large M_w 7.0 aftershock on Day 11. Reactivation of landslides caused by the main shock were again included using the best judgement of *Resilience to Nature's Challenges* researchers, based on the new aftershock sequence and a new rainfall sequence.

Scaling reduced the time and resources required to develop the scenario and association with *Project AF8*, which had acquired a high profile nationally following outreach efforts and articles being published in the press (e.g. Mitchell, 2017; Orchiston et al., 2018), generated interest in the AF8+ scenario-based participatory approach. However, there were also difficulties involved with scaling the *Project AF8* scenario. Particularly, deciding appropriate hazard intensity for the scenario was a matter of judgement for scientists (Section 4.4.1.1.2). Further, while *Project AF8* was intended to have one scenario, it was developed as sub-scenarios for six regional and one national emergency management workshops. This led to inconsistencies caused by creating seven sub-scenarios in a short space of time, including between the types of information presented, the phrasing of the information presented, the data specified for the same information between scenarios, and the timestamps at which information was presented both for different regions and between the scenario and GIS mapping. Discrepancies also developed due to the intended changing ("living document") nature of the AF8 scenario, designed to increase the relevance of the AF8 scenario by allowing workshops to reflect research outputs as they were produced, including accounting for real-world events which occurred between exercises, such as the November 2016 "Kaikōura" earthquake (Orchiston et al., 2016; Orchiston et al., 2018). These discrepancies fragmented the AF8 scenario, so that it was initially difficult to develop the AF8+ scenario from the AF8 scenario.

It is also worth cautioning that because the process used a single hazard scenario, scaling ran the risk of placing too much focus not only on a particular hazard but also on a particular faultline, given the prominence of *Project AF8*. On balance, using a "single" hazard scenario was deemed appropriate in part because the wider Franz Josef participatory disaster impact reduction process was considering other hazard events, including through the use of scenarios (Section 4.1). University academics were also able to stress in workshop presentations that other hazards needed to be considered, and particularly that the scenario-based participatory approach was focussing on impacts and that similar impacts could result from other large-scale events, including earthquakes originating from other faultlines, so it was felt that the scenario would not be considered by participants as the "only" natural hazard to prepare for (Section 4.4.1.1.1). Using a "single" scenario also helped reduce complexity within the process, and reduced resources required from the *Resilience to Nature's Challenges* researchers (including the participating academics).

4.4.2.1 Identifying participants

Franz Josef community members who were already actively involved in disaster impact reduction collaborations were invited to participate in recovery planning workshops. Participating community members also invited further community members to participate through word-of-mouth and emails via a community email list. Community members agreed to participate and agreed that the scenario-based approach was suitable and the AF8+ scenario was relevant (Section 4.1). In these discussions, University academics and Franz Josef community members collaboratively identified the need to focus on the distributed infrastructure dependence of Franz Josef in this process, and particularly road access, electricity supply and telecommunications. This was due to awareness of Franz Josef's dependence on the West Coast region's linear distributed infrastructure for service delivery, and of the relatively limited prior focus on distributed infrastructure within participatory disaster impact reduction processes within the town, and the national-scale implications of the scenario (Section 4.1).

At a West Coast Engineering Lifelines Group meeting, academics explained the proposed project, and members were invited to participate (full membership is detailed in Table 5). The West Coast Maintenance Contract Manager of the NZ Transport Agency (which is responsible for New Zealand's State Highway network), the general manager of Westpower (which is responsible for the majority of the West Coast electricity distribution) and regional CDEM Group emergency managers were invited to participate in workshops that focussed more intensively on their disaster response responsibilities (in addition to their participation as members of the West Coast Engineering Lifelines Group). Stakeholders within these organisations were asked to invite relevant stakeholders to participate. Emails were also sent to the CEOs of telecommunications providers and the national electricity transmission agency, inviting them to take part, but they declined to engage with the process.

University academics, selected on the basis of known aligned research interests and experience, were also invited to participate. These included Civil, Environmental and Geospatial Engineers, Collaborative Governance and Community Participation Social Scientists, Geomorphologists and Hazard, Risk and Resilience Scientists. The involvement of academics was partly enabled through the New Zealand Government Ministry of Business, Innovation and Employment *National Science Challenges* consortia research funding programme *Resilience to Nature's Challenges* (Table 5), which was designed to encourage cross-institution research collaboration.

4.4.2.2 Workshop sequence

The impacts scenario was co-created through a sequence of six workshops, held between October 2017 and March 2018 (Figure 42; Table 6). Different stakeholder groups (i.e. Franz Josef community members, Westpower, etc.) were invited to different workshops to allow stakeholder groups to co-create the impacts scenario in detail at a relevant scale. The date, time, location and duration of each workshop were agreed between the participating stakeholder group(s) for each workshop. This meant that workshops were held when, where and for a duration best suited the participating stakeholder groups, including the weekend as well as the week, in Franz Josef, Greymouth and Christchurch, and for half-days and full-days, to maximise participation.

The first four separate workshops were held with Franz Josef community members, Westpower, ground transport operators (NZ Transport Agency and KiwiRail) and the West Coast Engineering Lifelines Group, respectively. CDEM representatives and University academics participated in all workshops. Following the first four workshops, the NZ Transport Agency independently organised an additional workshop with two of its West Coast region subcontractors, Fulton Hogan and MBD Construction, and followed a similar methodology (Section 4.4.2.3). One academic (the lead facilitator) participated in this workshop. CDEM representatives did not attend this workshop. Finally, a "combined" workshop was attended by academics, CDEM, Franz Josef community members, Fulton Hogan, NZ Transport Agency, Westland District Council, and Westpower.

After each workshop, summary notes and the impacts assessment maps were compiled and sent to the workshop participants to corroborate findings, correct records of the workshops, and to provide feedback. An end-to-end disaster impact reduction modelling framework for infrastructure networks was also integrated with the process to enhance workshop discussions. After workshops, the workshop recovery estimates were input into this framework and network interdependencies of 11 infrastructure networks were modelled. This modelling was then shown to participants at subsequent workshops, to inform their impacts estimates. Integration of this independent academic initiative into this participatory process is discussed in full in Chapter 5.

In each subsequent workshop, the findings of previous workshops and the integrated modelling were relayed to the participants. The impact maps created in previous workshops were also available to view. This created a shared understanding which allowed workshop participants to build on the findings of the previous workshops both in the workshop, as well as for real world application.

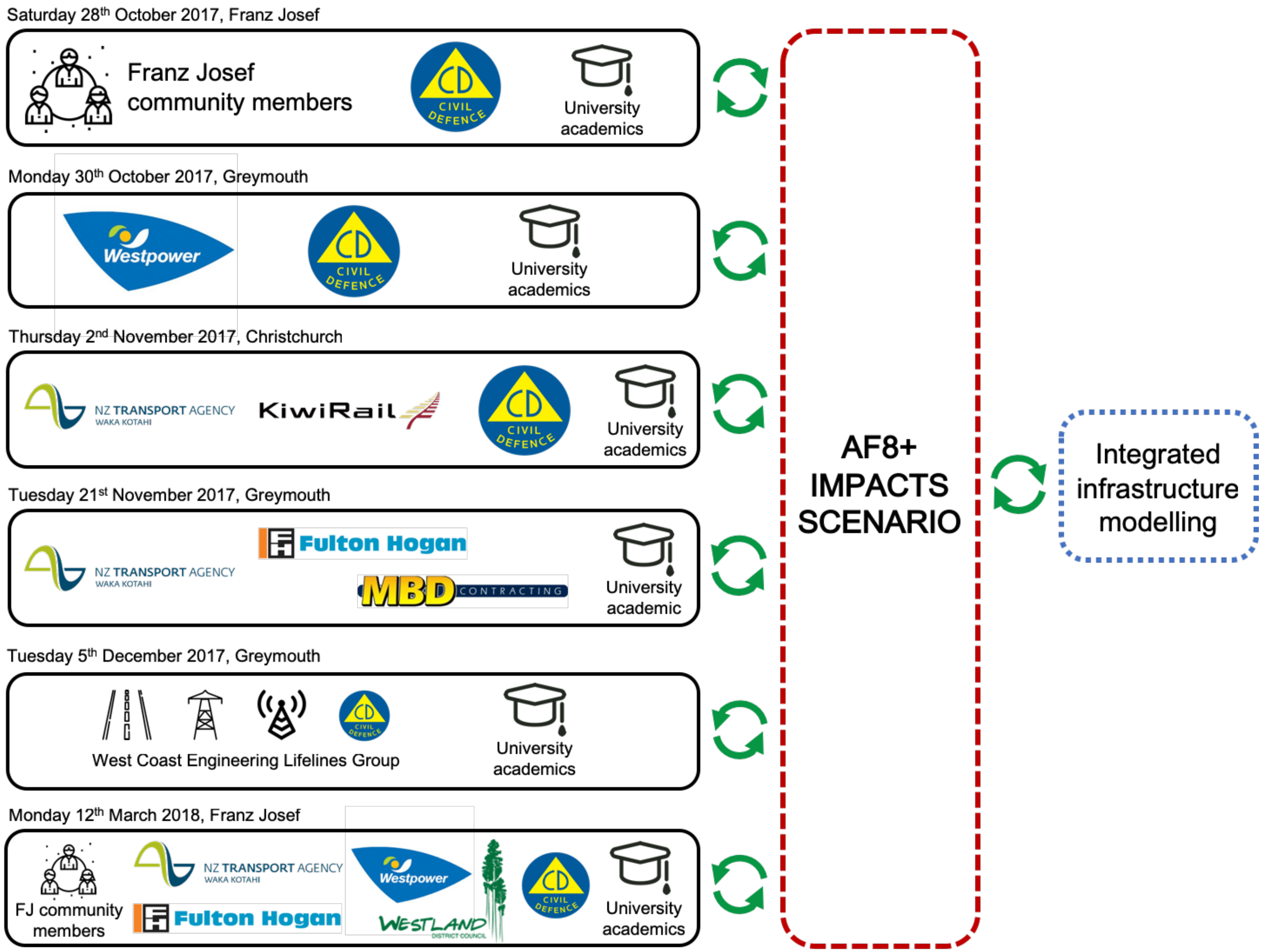

Figure 42. Schematic of the AF8+ scenario-based participatory approach workshops sequence (each solid box represents a workshop). Each workshop co-created the impacts scenario. Workshops used the findings of previous workshops to inform the impacts scenario. Recovery estimates were also input into an integrated framework to model infrastructure interdependencies (Chapter 5) which iteratively informed the impacts scenario and future workshops.

Table 6. Summary of the AF8+ scenario-based participatory approach workshops.

Date	Location	Attendance	Purpose	Scale
Saturday 28th October 2017	Franz Josef	Academics; Franz Josef community members; West Coast CDEM.	Establish Franz Josef's post-disaster resource levels.	Local
Monday 30th October 2017	Greymouth	Academics; West Coast CDEM; Westpower.	Establish West Coast region electricity post-disaster service levels and recovery strategy.	Regional
Thursday 2nd November 2017	Christchurch	Academics; Canterbury CDEM; KiwiRail; NZ Transport Agency.	Establish South Island ground transport post-disaster service levels and recovery strategy.	National
Tuesday 21st November 2017	Greymouth	Academics; West Coast Engineering Lifelines Group (including District Councils; NZ Transport Agency; West Coast CDEM; Westland Milk Products; Westpower).	Establish West Coast post-disaster service levels and recovery strategies, focussing on interdependencies.	Regional
Tuesday 5th December 2017	Greymouth	Academics; Fulton Hogan; MBD Contracting; NZ Transport Agency.	Corroborate West Coast State Highways' post-disaster service levels and recovery strategy.	Regional
Monday 12th March 2018	Franz Josef	Academics; Franz Josef community members; Fulton Hogan; NZ Transport Agency; West Coast CDEM; Westland District Council; Westpower.	Enable discussion and collaboration to improve the resilience of Franz Josef.	Local

4.4.2.3 Workshop design

Prior to each workshop, the workshop design was proposed by University academics (modelled on the workshop design of Johnston et al., 2006), and then discussed and revised with participants. This meant that the design of each workshop, including the participation methodologies used within the workshops, was tailored to the participating stakeholder group(s). The project background, ethics form and (revised) workshop design were then sent to all participants. Participants were also advised to bring anything which could be valuable to the workshop (e.g. organisation or community Civil Defence & Emergency Management response plans).

Each workshop was structured in two phases. The first phase was facilitated using the essentialist method and the second phase was facilitated using the social constructionist method (Wodak & Neale, 2015; Section 4.4.1.2), as follows:

4.4.2.3.1 Workshop Phase 1: Presentation led by facilitator (the essentialist method)

A. **Present project background, ensure ethics are discussed and forms are completed, discuss plan for the workshop.**
All participants were provided with background to the project and the plan for the workshop was discussed and modified, based on stakeholder priorities.

B. **Present the hazard scenario (PowerPoint) and exposure maps.**
The AF8+ hazard scenario was communicated in the form of a PowerPoint presentation and exposure maps showing where hazards impacted infrastructure networks and buildings (Section 4.4.2.1). Exposure maps were produced at the local scale for Franz Josef, at the regional scale for West Coast electricity poles, and at the national scale for South Island State Highways (the South Island rail network was also shown in relation to hazards estimated for the State Highways, as the rail network approximately follows State Highways). These maps are shown in full in Appendix F. The Franz Josef exposure map was detailed for t = 1 day. The electricity and ground transportation exposure maps were detailed in 10 timesteps, as follows:
   - t = 1 day (1 day);
   - t = 1 week (7 days);
   - t = 1 month (30 days);
   - t = 6 months (183 days);
   - t = 1 year (365 days);
   - t = 2 years (730 days);
   - t = 3 years (1095 days);
   - t = 4 years (1461 days);
   - t = 5 years (1826 days);
   - t = 10 years (3652 days).

4.4.2.3.2 Workshop Phase 2: Participant-led impacts discussion (the social constructionist method)

A. Participants discuss and clarify hazard scenario.
Following the scenario presentation, participants clarified background to the hazard scenario, including discussing comparable hazards and impacts and scenario uncertainties. These answers were predominantly provided by the academics who were involved in the development of the scenario.

B. Participants discuss and refine impacts scenario assumptions.
The participants used the exposure maps to discuss and define the impacts to relevant buildings and infrastructure. For example, deciding the size of landslides and deciding whether a bridge exposed to a hazard would collapse or not.

C. Participants detail the impacts scenario, modifying the exposure maps.
Participants discussed and co-created the impact scenario at the scale most suited to the stakeholder group, including by modifying the exposure maps to create impacts maps. Within the infrastructure workshops, these impacts maps were detailed as infrastructure service levels through time.

4.5 Results

4.5.1 Franz Josef community workshop, Saturday 28th October 2017

The Franz Josef workshop was run in collaboration with the West Coast CDEM Group as a “Civil Defence Day” in Franz Josef. To maximise participation and increase relevance, this workshop was held on a Saturday, was only half a day long, and was adjusted to also include a simulation-style injects-based exercise (using the AF8+ scenario) as community members felt that they had not had enough practice at emergency response. The day started with response training, including operations and equipment checks. Towards the end of the simulation exercise, Franz Josef community members then detailed the expected number of people in the town, an evacuation plan, communications resources, transport resources, as well as supplies, in days, of food, water, fuel and medications. Full summary notes are provided in Appendix G1. Key outcomes included that the participating community members expected Franz Josef to have:

- 2000 tourists to account for and evacuate;
- 3 satellite phones;
- 5 helicopters;
- 48 hours triage medical supplies;
- 4 days of food for tourists;
- 2 weeks of food for residents;
- 10 days of diesel; and
- 20 days of petrol.

Throughout the workshop, community members also itemised several actions for future work, including:

- "Need full inventory of medication needs to enable stocks. Also need to increase medical supplies for a mass casualties event.
- "Need a list of sat phone numbers, and contact phone numbers for neighbouring towns and local volunteers (for when mobile coverage remains available).
- "Regular commitment to scenario training twice a year.
- "It would be good to run a similar process with other towns, including Fox Glacier, Ōkārito and Whataroa."

4.5.2 Westpower workshop, Monday 30th October 2017

The Westpower workshop was run as a day-long workshop in Greymouth and focussed on Westpower's electricity network. The scenario co-creation began with a detailed discussion between Westpower and CDEM about response and readiness. This included discussions about the emergency supplies requirements for Westpower staff, and relative priorities for reconnaissance data collection amongst lifeline utilities.

Westpower stakeholders noted that the repair of their electricity network is dependent upon the national supply and road access. As the first infrastructure provider contributing to the AF8+ scenario, both of these dependencies had to be assumed in the workshop. Full summary notes from the workshop are detailed in Appendix G2. Key scenario findings were as follows:

- After one week, without replenishment of supplies and gear (poles, cross arms, fuel etc.) Westpower would run out of supplies and be unable to continue repairs. The repair operation would go backwards as if substations run out of (back-up) power supply, they may not be able to be restored.
- Within one month, mains power is expected to be restored to Franz Josef if the Waihapo power plant is still generating.
- Within six months, participants were fairly confident that all power stations between the top of Westpower's region down to Franz Josef would be restored. Fox Glacier would have an isolated power supply. The restoration of the electricity south of Franz Josef would depend on government priorities and road access. This would be a large investment across a large area for a small population.

Throughout the workshop, Westpower stakeholders also itemised several actions for future work. These included:

- "Plan for Emergency Management Team set-up pre-event, including ensuring vital staff are prepared at home to get the Emergency Management Team up running quicker.
- "Pre-plan reconnaissance flight routes (West Coast CDEM-led).
- "Westpower GIS needs to be compatible with CDEM GIS.

- “Design remote shut down switch for substations (particularly for minor, not GXP substations)
- “Stocktake and source generators for substations.”

4.5.3 Ground Transport workshops, Thursday 2nd November and Tuesday 5th December 2017

The first Ground Transport workshop was run as a day-long workshop in NZ Transport Agency’s Christchurch office and focussed on South Island State Highways and rail infrastructure. This workshop heavily recalled lessons from the 2016 “Kaikōura” earthquake (e.g. Chapter 3) to inform the assessment of the scenario impacts. Full summary notes from the workshop are included in Appendix G3. Key scenario findings were as follows:

- All ground transport access to the West Coast will be closed for weeks.
- Limited public road access to Franz Josef is expected to be restored within six months.
- After restoring access to Franz Josef, NZ Transport Agency would prioritise the repair and improvement of re-opened roads over re-opening other damaged roads, unless the Government made these roads a priority.
- Permanent road closures may occur, including Arthurs Pass, Haast Pass to Franz Josef and the Coast Road between Greymouth and Westport. Restoration of these routes would depend on long-term government priorities.
- Permanent closure of the rail network west of Springfield may occur, depending on government priorities. Without road access through Arthur’s Pass, the rail cannot be repaired.

Throughout the workshop, NZ Transport Agency stakeholders also itemised several actions for future work. These included:

- “NZ Transport Agency is keen for a communication strategy with communities, particularly around possibilities of managed retreat of infrastructure following disasters.
- “Seek community resilience solutions to future events, some of which can be implemented pre-event
- “Work with CDEM to ensure effective use of helicopters in a response.
- “Surge capacity of contractors needs greater consideration.
- “Cost out possible alternative routes before major events occur so that managed retreat can be implemented afterwards. These can be pre-approved by NZ Transport Agency board so that after a disaster, alternative routes may be built instead of repairing old (destroyed) roads, if they are found to be more cost-effective and offer longer-term resilience.
- “Work with other lifeline utilities on interdependencies.”

NZ Transport Agency also independently organised a half-day workshop with its West Coast region subcontractors (Fulton Hogan and MBD Construction) in the NZ Transport Agency Greymouth office. NZ Transport Agency led the facilitation of this workshop and initially ran the workshop “blind”, without revealing previous workshops’ findings, to corroborate the findings of NZ Transport Agency’s national planners. Subsequently, the findings of the ground transportation workshop were provided and discussed. The contractors agreed with the findings of the first Ground Transport workshop. Full summary notes from the workshop are included in Appendix G3. The contractors also raised additional items for future work, including:

- “Contractors are assuming Health and Safety and resource consents may be critical to repair times. It would be good to consider and plan for these in advance.
- “Closing the road (without any form of public access) for longer will speed recovery. This is a value judgement worth discussing.”

4.5.4 West Coast Engineering Lifelines Group, Tuesday 21st November 2017

The West Coast Engineering Lifelines Group workshop was run as a half-day workshop in Greymouth, following a quarterly meeting of the group in the morning. The focus of this workshop was to discuss interdependencies between the State Highways, rail, and Westpower electricity networks’ impact assessments, co-created in previous workshops, and also to discuss the interdependencies between these networks and the other lifeline utilities. Telecommunications were noted as a key dependency. Unfortunately, telecommunications providers did not attend the workshop, limiting both assessment of telecommunications outages and recovery times. Full summary notes from the workshop are included in Appendix G4. Key scenario findings were as follows:

- “Westland Milk Products and the West Coast mining industry rely on overseas contracts to buy and supply products and remain profitable. They will not be able to access or supply products if Arthurs Pass is closed. If this is the case, they expect to lose essential overseas contracts, and they do not have insurance cover for loss of overseas customers.
- “Rail is critical to the long-term survivability of the milk and mining industry on the West Coast.
- “Fuel management will be critical for all lifelines with no or limited road access”

Through collaborative discussions in the workshop (as well as throughout the workshops), disaster impact reduction strategies were also co-created. These included:

- “Share Business Continuity Plans and Emergency Management Plans of local businesses and lifelines.
- “Improve understanding of key agreements with service and resource providers, i.e. fuel, food and aid.
- “Fuel supply is a key dependency that requires pre-disaster planning.”

4.5.5 “Combined” workshop, Monday 12th March 2018

The final workshop in this process brought together representatives from all stakeholder groups that had participated in the previous AF8+ workshops, for the first time in the process. This was a half-day workshop, held in Franz Josef. Prior to this workshop, all participants were sent a slideshow containing a summary of the outcomes from the previous workshops, which were presented in full at the beginning of the workshop. In the workshop, each stakeholder group's scenario assessments were presented and discussed. With all stakeholder groups participating, each group could lead or respond to discussions on their area of expertise.

Workshop discussions focussed on implications for the Franz Josef community and regional infrastructure by leveraging the detailed national-, regional- and local-scale assessments already completed within the targeted workshops. Through collaborative discussions in the workshop, disaster impact reduction strategies were co-created. For example, Franz Josef community members identified that they would be severely impacted locally, have limited resources and a large population to support, and would be isolated. Practitioners were able to confirm that the community would be inaccessible via ground transportation (i.e. State Highways) for months (Figure 50). Subsequently, the community identified that they could self-ration to ensure that supplies would last and road operators identified that, due to the magnitude of regional damage, it would be more beneficial for locally-based roading contractors to help repair local infrastructure, including local roads, water pipes, sewerage, etc., than attempting to open the State Highways, as this would require a structured, centrally-led and resourced response. Complete workshop summary notes are provided in Appendix G.

In addition to these core discussions, the workshop also included valuable discussions of "background" New Zealand hazard events, with participants keen to learn from these events and apply the lessons to the planning process. For example, impacts of and recovery strategies following two ex-cyclone events (Fehi and Gita) in February 2018 were discussed, to inform future responses. This included Westpower noting that it takes longer to repair powerlines when people drive on (closed) roads, as their crews have to stop working due to the danger this causes. Subsequently, the community members noted that they could try to reduce people from driving on roads when they are closed to help speed electricity recovery times.

Community members, practitioners and policymakers all noted the value of the workshop. For example, a Franz Josef business owner also noted that, "from a business point of view, knowing likely outage times (as shown in the maps used in the workshop) is very useful for crisis management", and NZ Transport Agency and Westpower noted that the workshop was a valuable opportunity to discuss the infrastructure providers' best-case assessment of what may reasonably be possible after the scenario event presented, providing a rough order of likely work progression, to assist community members with their preparedness, response and recovery planning.

Notably, the importance of the summary notes and ongoing collaborative relationships between stakeholders as participatory methodologies beyond the workshops was highlighted after the "combined" workshop. There were particular difficulties arranging this workshop due to the two ex-cyclone events, which meant that, although all stakeholder groups were represented, some key stakeholders were unable to attend the workshop due to a clash with an event debrief. Subsequently, when stakeholders who were unable to attend the meeting received the workshop summary notes, concerns were expressed over inaccuracies in the information discussed in the meeting. Here, the workshop notes had highlighted gaps in shared understanding which had not been recognised in the meeting. The workshop notes therefore enabled these gaps to be addressed by the stakeholders.

4.5.6 Infrastructure outage maps

The scenario-based participatory approach produced network outages over time[1], shown below. West Coast regional electricity outages are shown in Figure 49. South Island State Highway outages are shown in Figure 50. South Island rail network outages were also established but are not shown because it was expected that there would be rail service on the north to south line and no rail service on the East-West line, including the West Coast, west of Springfield for several years.

[1] **Disclaimer:** The AF8+ scenario, co-created and used to enable discussion and collaboration within workshops, is designed to provide an example of an extreme earthquake for response and recovery planning in the South Island of New Zealand, with a focus on the West Coast and Franz Josef township. It is a realistic but extreme-case scenario, detailing earthquakes and their associated ground motions, landslides, and transposed real-world aftershock and rainfall sequences. The AF8+ scenario was compiled using the best scientific knowledge currently available (Orchiston et al., 2016). It is important to stress these maps detail expectations based on individual and collective understandings of the AF8+ hazard scenario, which was co-created into impacts scenarios within workshops. Recovery strategies and service levels were estimated in workshops for this AF8+ scenario only.

It is vital to understand that the AF8+ scenario is **NOT A PREDICTION** of what will happen during and after the next major earthquake that affects the West Coast (which may not be on the Alpine Fault). The underlying philosophy is that if we plan for an extreme case, we improve our ability to cope with less severe events ("expect the worst, hope for the best").

AF8+ scenario Westpower levels of service

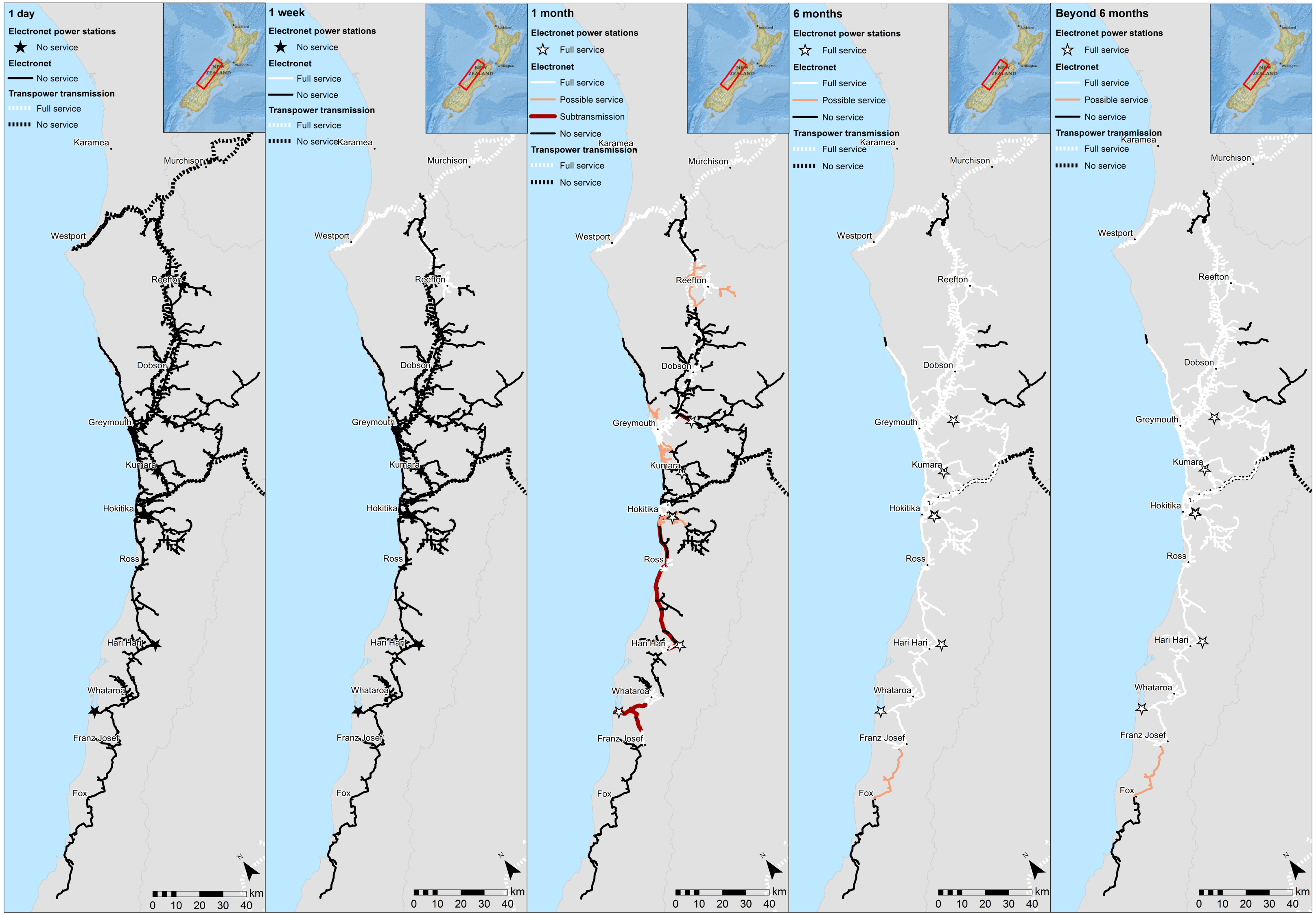

Figure 43. The co-created AF8+ impact scenario for Westpower electricity service levels.

AF8+ scenario State Highway levels of service

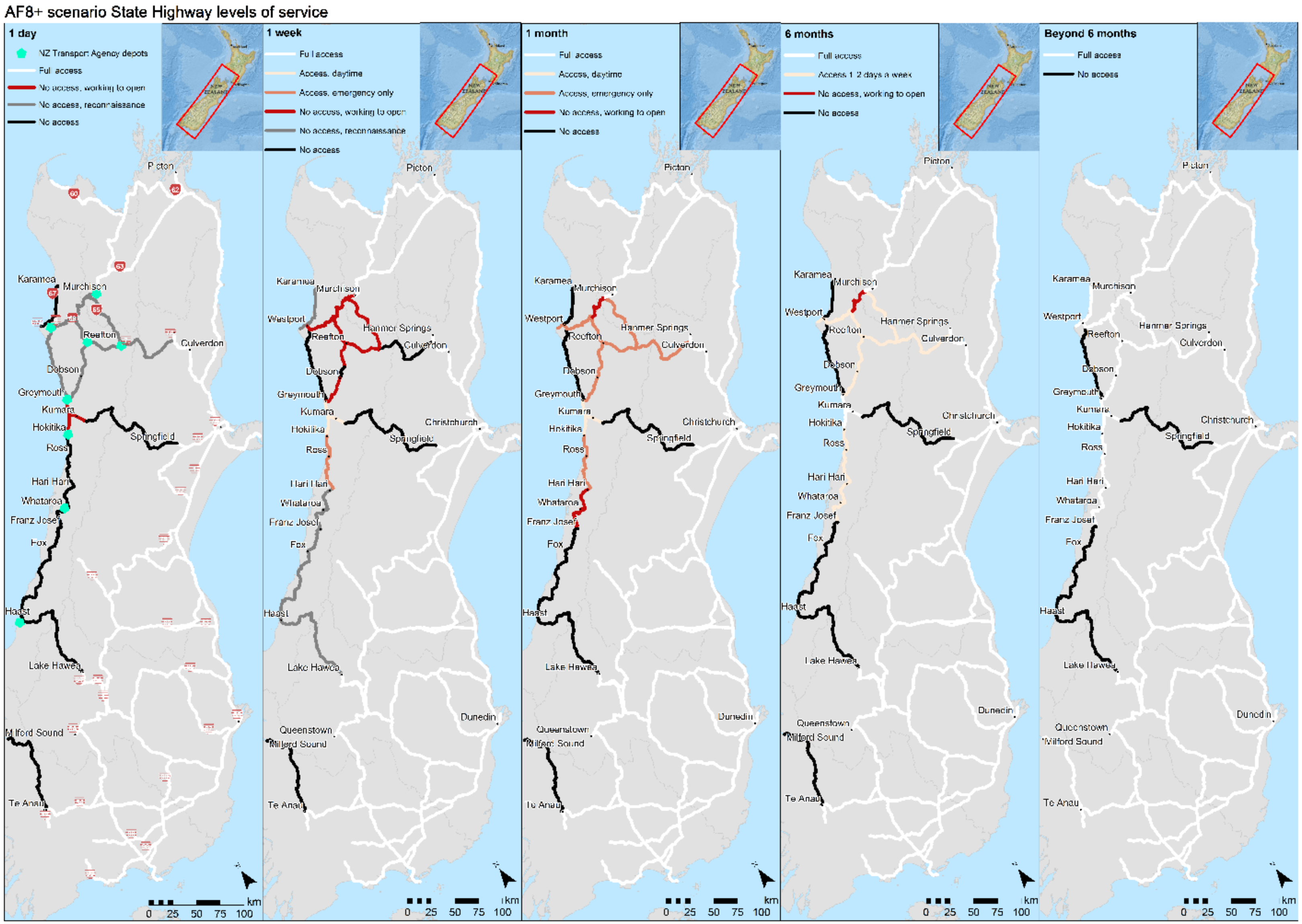

Figure 44. The co-created AF8+ impact maps for South Island state highways' service levels.

4.6 Discussion

The transferrable scenario-based participatory approach described in the previous sections utilised an earthquake scenario as a boundary object. This allowed all stakeholder groups to inform the development of integrated knowledge concerning the likely disaster impacts, and decision-making required to reduce them. This approach was applied in a “pre-disaster” collaboration (the AF8+ scenario-based participatory approach) which integrated and balanced the knowledge of community members with and alongside that of infrastructure providers, emergency managers, local government policymakers, and academics. Balancing and appropriately sequencing the influence of these stakeholders ensured that the resulting knowledge was recognised as relevant and credible by all involved. In doing so, the process encouraged a proactive increase in the disaster resilience of Franz Josef and distributed infrastructure networks and so the resilience of the West Coast region of New Zealand.

4.6.1 Participatory design: Sequencing scenario-based participation

Sequencing of the workshops was critical to the process outcomes. Running a sequence of workshops with a combination of methodologies allowed workshops to be scheduled to maximise participation for every stakeholder group. For example, most workshops were held on weekdays, but the community-specific workshop was held on the weekend, respectively allowing each stakeholder group to organise their targeted workshops when best suited them, enabling both higher levels of participation and participation from the people the stakeholders considered critical to informing the process. Further, sequencing workshops allowed the impacts scenario to be co-created at the scale most relevant to the stakeholder group, focussed on the stakeholder group’s area of interest (i.e. the Franz Josef community focussed on Franz Josef, NZ Transport Agency focussed on State Highways, etc.). This respectively enabled deep, detailed discussions of community and technical issues, ensuring that the workshop was highly relevant for the stakeholder groups. Moreover, these advantages ensured that stakeholder groups had more influence in their own area of expertise. Therefore, sequencing enabled balanced participation between stakeholder groups, increasing the credibility and legitimacy of the process.

The impacts scenario that was generated through this process was then able to be used as a boundary object, enabling the translation of often technical knowledge into forms accessible and useful for all stakeholder groups (Star & Griesemer, 1989). As anticipated, the scenario was a successful form of translation between stakeholder groups, enabling the integration of previously siloed local and technical knowledge (Section 4.3). For example, a Franz Josef business owner noted that “from a business point of view, knowing likely outage times (as shown in the maps used in the workshop) is very useful for crisis management”. In this way, the impacts scenario created a shared understanding.

Subsequently, sequencing generated an iterative dynamic, as stakeholders were able to use the shared understanding to improve their impacts assessment. For example, in the West Coast Engineering Lifelines workshop, with improved understanding of road outages, Westpower were able to improve their recovery estimates. Further, stakeholders were able to utilise the shared understanding to immediately improve their disaster impact management measures in the real world. For example, in the combined workshop, Westpower noted that after a disaster, it takes longer to repair powerlines when people drive on (closed) roads, as their crews have to stop working due to the danger this causes. Subsequently, the community members noted that they could try to reduce people from driving on roads when they are closed to help speed electricity recovery times. Moreover, individual stakeholder groups were able to act on the shared understanding to improve their understanding of disaster impacts after the workshops. Either at subsequent workshops, or through feedback to the facilitator, this new knowledge was also able to inform the impacts scenario, enhancing the shared understanding. This iterative integration of knowledge continuously improved the understanding of stakeholders, allowing them to contribute to an improved understanding through knock-on implications, in a feedback loop. This was best demonstrated by integrated infrastructure modelling, which used recovery estimates to inform network interdependency modelling, which was iteratively integrated into the scenario workshops where it was discussed and produced revised recovery estimates, in a feedback loop. In doing so, stakeholder input verified and highlighted areas for improvement in the modelling, and the modelling verified and highlighted areas for improvement in the stakeholder knowledge, improving both. This process is described in detail in Chapter 5.

Critically, in ensuring inputs were credible, legitimate and balanced, the stakeholders trusted the inputs as genuine needs and priorities and fully engaged with these to develop disaster impact reduction measures. This formed trusting relationships between the participants, who could see simply by participating in the process that the other stakeholder groups were acting to address resilience. This was particularly notable in the “combined” workshop, where infrastructure providers were able to see the commitment from the large number of community members to increase the resilience of Franz Josef, and the community members were able to put names and faces to organisation names and find out who was responsible for various disaster impact reduction initiatives.

Overall, the willingness shown by stakeholders to participate was critical to this successful implementation of the AF8+ scenario-based participatory process. Both researchers and participants invested large amounts of time specifically for this process, establishing new relationships and strengthening many existing relationships. The drive and unwavering commitment demonstrated by the community members who started the process and remained determined to increase the resilience of Franz Josef were particularly critical. These are likely to have been partly enabled by the tight-knit and remote character of the community, as community members with place attachment and strong connections between community members (including government) have similarly been found by others to assist participatory approaches by helping to ensure compromises for the good of the community (Aoki, 2018; Espiner & Becken, 2014; Orchiston, 2013). The application of this approach also benefitted from New Zealand’s strong “lifelines” culture. Lifeline utilities are legislated to improve disaster readiness, reduction, response, and recovery in New Zealand (CDEM Act 2002). But the success of this voluntary scenario-based process also relied heavily on the willingness of the West Coast Engineering Lifelines Group, and in particular NZ Transport Agency and Westpower, alongside regional CDEM Groups to go beyond the responsibilities required under this legislation by demonstrating commendable leadership and commitment. In this way, the AF8+ scenario-based participatory approach clearly benefitted from strong, trusting relationships.

The AF8+ scenario-based participatory approach thus successfully demonstrated the proposed methodology, demonstrating the ability to co-create knowledge which in turn can inform decision-making. Sequencing participation allowed the impacts scenario to act as a boundary object between community members, practitioners, policymakers and researchers. In doing so, the approach led to the benefits previously observed for scenario-based collaborations between practitioners, policymakers and experts (Section 4.3), namely:

1) knowledge co-production, which challenged prevailing assumptions and identified new risks, vulnerabilities, and resilience solutions;
2) the implementation of resilience measures; and,
3) the establishment and growth of relationships with and between community members, infrastructure providers, emergency managers, local government policymakers, and researchers.

4.6.2 Limitations

Despite successfully demonstrating the proposed methodology, the application was not without its shortcomings. First, the process would have benefitted from more diverse participation methodologies, for example, by holding open meetings or using surveys in addition to the workshops (Aoki, 2018). Workshop notes and stakeholder feedback were critical to the success of the participation methodology, despite not being an initial focus of the methodological approach. Further, Aoki (2018) finds that combining different participation methodologies means that participants who can commit more time are encouraged to do so, but those who cannot commit the same amount of time can still participate, and do not have to be excluded from the process entirely. More participation methodologies therefore likely would have increased participation, increasing credibility and the opportunity to grow the shared understanding. Similarly, whilst not a focus of this study, multiple participation methodologies may have helped balance pre-existing social power relations and dynamics.

Second, only the “relevant” stakeholders were invited to workshops. While mostly driven by increased convenience, the “closed” nature of many of the workshops was in part driven by a concern about negative publicity, given that discussing disasters and response strategies can be a sensitive topic. “Closed” workshops had the advantage of ensuring that each stakeholder group was able to discuss their views openly, and if necessary, confidentially. However, Aoki (2018) provides evidence that allowing all stakeholders to participate in all parts of a process (enabled by varying influence weightings, such as only participating as observers) can increase trust in decision-making and speed up the overarching process, as fewer questions need to be asked about how and why decisions are or were made. It is worth noting that this requires greater “buy-in” from participating stakeholder groups, along with sustained interest. However, again, the often “tight-knit” character of remote communities can help to enable participatory governance (Chapter 2). Therefore, while the process, and particularly the “combined” workshop, disseminated outcomes from previous workshops, the process may have benefitted from allowing all stakeholders to participate in all parts of the process. This could feasibly be enabled through livestreaming of workshops to social media, as well as by inviting participants to observe additional workshops.

Third, with hindsight, the sequence of the workshops could also have been improved. While the lifelines workshop and “combined” workshop allowed direct discussions of interdependencies, holding the workshops in order of reducing scale (i.e. national, then regional, then local) would have reduced the assumptions required within the initial workshops. For example, Westpower is heavily reliant on State Highways to repair the electricity network, including the need to bring resources into the West Coast from other parts of the country. However, because their targeted workshop was held before the national-scale NZ Transport Agency workshops, they could not draw on this key stakeholder group’s knowledge, meaning that their initial restoration estimates relied heavily on assumptions about State Highways restoration times.

The fundamental logistical difficulties associated with, and time investment required for, participatory processes were also highlighted. Despite advantageous existing stakeholder relationships and the investment of a substantial amount of time in relationship building, it was not possible to engage all identified key stakeholders, including any telecommunications providers or the national electricity transmission agency. This increased the influence of other stakeholders, particularly researchers, on the scenario, as the judgement of others was used as a substitute for those who did not participate. This decreased the credibility of the scenario. Ultimately, though, this example highlights the vulnerability of the approach due to its voluntary nature.

Finally, there was little structured stakeholder evaluation of the scenario-based participatory approach. In each AF8+ workshop, feedback was encouraged at all times through a “feedback station” and at the end of each workshop there was also a brief discussion where participants were again invited to provide feedback. The research team also kept in very close contact with participants from all of the stakeholder groups throughout. This provided important feedback which could be, and was, used dynamically throughout the process (Chapter 4). However, such feedback remains limited in its scope to evaluate the approach and its outcomes. What constitutes successful scenario planning is different for different people, and so is challenging, contentious, and worthy of (more detailed) evaluation by all participants (Reed et al., 2008; Wodak & Neale, 2015). For example, whether and how to involve participants in designing the evaluation of the project remains unclear (Blackstock et al., 2007; Reed, 2008; Webler & Tuler, 2006). This problem is not unique to scenario planning. There is a lack of evaluation criteria and structured data collection methods for transdisciplinary research in general (Holzer et al., 2018; Reed, 2008). Most commonly, evaluations of transdisciplinary research have focussed on evaluating the methodology and techniques, despite general agreement within the literature that evaluation of transdisciplinary projects should consider both the study's process and outcomes (Holzer et al., 2018; Reed, 2008; Wodak & Neale, 2015). Reed (2008) argues that this may be because selecting appropriate criteria and data collections is difficult. To address this gap, Holzer et al. (2018, p. 812) conducted a literature review of evaluation techniques across 'a variety of fields of study and practice', and organised these into five categories: customised questionnaire; integrative mixed methods; staged environmental program evaluation; research embedment and performance profile; and case study. No comprehensive techniques for evaluating transdisciplinary outcomes were found, so Holzer et al. (2018) propose a technique. However, because this proposal is so recent, there is no consensus around whether this is an appropriate evaluation technique to assess the outcomes of transdisciplinary research (it is noted that the technique is tailored towards socio-ecological studies). While this is not a gap the present research seeks to address, it is acknowledged that the evaluation of transdisciplinary research outcomes remains an important matter for future studies to address.

4.6.3 Future work

Notably, this research project benefitted from two key influences which aided implementation. First, the application of this approach particularly benefitted from New Zealand's strong "lifelines" culture. As discussed above, lifeline utilities are legislated to improve disaster readiness, reduction, response, and recovery in New Zealand (MCDEM, 2002), but the additional leadership and willingness to participate in this process shown by the West Coast Engineering Lifelines Group, and in particular NZ Transport Agency and Westpower, alongside regional CDEM Groups, was essential to the success of this voluntary process. Second, both the *National Science Challenge Resilience to Nature's Challenges* and *Project AF8* are major national research programmes (Chapter 4), which gave this research project and the Franz Josef community national prominence and made the community a focal point for resilience planning in the West Coast region. This created a unique situation, backed by substantial resources, including financial resource which councils typically cannot afford to spend. Accordingly, this created an unusual situation, where the researcher involvement likely had a positive influence on resilience planning for the community, both in terms of available resources and influence on both policymakers and practitioners to participate.

However, despite these influences, the approach still suffered when infrastructure stakeholders either did not or could not engage with the process due to other priorities. High staff turnover (alongside community members) and sustaining interest also presented challenges. As discussed above, the lack of engagement from some stakeholder groups decreased the scenario credibility and increased the influence of other stakeholders, particularly researchers, on the scenario, as their judgement was used as a substitute for those who did not participate. Further, while the research project stopped short of efforts to maintain collaboration (Section 4.6.2), the collaborative process has also not been picked up by policymakers or practitioners. As researchers led the process but stopped short of efforts to establish sustain collaboration, without leadership from a stakeholder group, the benefits of the application may be short-lived. Equally, the developed approach, which could be used with other communities, has not been, despite explicit requests from community members from Fox Glacier, Ōkārito, and Whataroa, as well as requests from infrastructure companies which desire collaboration with community members.

While part of the project's success was due to the close collaboration between researchers and the West Coast Engineering Lifelines Group, closer collaboration could have encouraged more participation. For example, making the project a formal West Coast Engineering Lifelines Group project may have encouraged participation from telecommunications providers. Legislation is also an option which has been successful in New Zealand at effectively mandating collaboration between infrastructure companies and emergency managers (MCDEM, 2002). Clarifying and, if necessary, strengthening this mandate could greatly increase necessary collaboration between community members and lifelines organisations. This is a well-established need, which has also been identified as particularly critical for remote, potentially-isolated communities (Chapter 2). CDEM Groups are well-positioned to lead such collaborative work, but face resource constraints. Participatory processes require substantial time, trained staff, and financial resources which can limit implementation. Therefore, the low resources currently afforded to CDEM Groups suggest that the current system may not be optimal for the resilience of remote communities in New Zealand.

The developed approach also has applicability beyond remote communities alone. For example, applying the approach to other sudden-onset hazards, such as avalanches, debris flows, flash floods, volcanic lahars, and tsunami, may be particularly rewarding. Communities dealing with sudden-onset hazards are, similarly to remote communities, likely to be alone when responding to warnings and the first to respond to a disaster. Further, the research has applicability to managed retreat discussions in general, including those focussed around climate change. Again, for managed retreat to succeed, community members must adopt and take ownership of the initiative (Few et al., 2007), which this approach enables.

4.7 Conclusions

- A participatory approach was developed, utilising a scenario as a boundary object, allowing relevant, credible and legitimate decision-making across all stakeholder groups (Cash et al., 2003) by combining and sequencing various (existing) participation methodologies (Aoki, 2018).
- Both infrastructure companies and community members explicitly asked for collaborative processes between community members, practitioners and policymakers. This is a well-established need, which has also been identified as particularly critical for remote, potentially-isolated communities (Chapter 2).
- The developed approach was applied in a "pre-disaster" collaboration: the AF8+ scenario-based participatory approach. This approach successfully integrated and balanced the knowledge of community members with and alongside that of infrastructure providers,

emergency managers, local government policymakers and researchers to proactively increase resilience to naturally-triggered disasters. Accordingly, the process demonstrated the ability to co-create knowledge which in turn can inform decision-making. Further, the process also directly increased the resilience of Franz Josef and the regional resilience of distributed infrastructure networks through stakeholders utilising the developed shared understanding.

- Balancing the integration of knowledge between stakeholders is critical to the success of participatory processes (Ackerman, 2004; Reed et al., 2013), particularly in remote communities (Chapter 2), but has previously been difficult to achieve. Sequencing participatory methodologies within the scenario-based participatory approach allowed stakeholders to engage with and gain more influence over the process at their relevant scale (i.e. local, regional, or national), as well as enabling the process design to better suit the participation capacities of the stakeholder groups. In this way, combining and sequencing enabled the knowledge of community members to be integrated and balanced with and alongside that of practitioners, policymakers and researchers.
- Combining and sequencing also enabled feedback loops. In this way, stakeholder groups could iteratively build on the impacts scenario, co-producing knowledge across knowledge spheres. Moreover, because stakeholders could understand other stakeholders' contributions, stakeholders were able to utilise these contributions immediately to assess existing and implement new resilience measures in the "real world".
- The process built trusting relationships between stakeholder groups. In ensuring inputs were credible, legitimate and balanced, the stakeholders trusted the inputs as genuine needs and priorities and fully engaged with these to develop disaster impact reduction measures. This formed trusting relationships between the participants, who could see simply by participating in the process that the other stakeholder groups were acting to improve resilience. This was particularly notable in the "combined" workshop, where infrastructure providers were able to see the commitment from the large number of community members to increase the resilience of Franz Josef, and the community members were able to put names and faces to organisation names and find out who was responsible for various disaster impact reduction initiatives.
- However, the approach was limited by its voluntary nature, and stopped short of attempting to enable ongoing participation. Without leadership from a stakeholder group, the benefits of the application may be short-lived (Blake et al., 2011; Fenwick, 2012; Robinson et al., 2014). Closer collaboration could have encouraged more stakeholders to participate. For example, making the project a formal West Coast Engineering Lifelines Group project may have encouraged participation from telecommunications providers. Legislation is also an option which has been successful in New Zealand at effectively mandating collaboration between infrastructure companies and emergency managers (MCDEM, 2002). Clarifying and, if necessary, strengthening this mandate could greatly increase necessary collaboration between community members and lifelines organisations. CDEM Groups are well-positioned

to lead such collaborative work, but face resource constraints. Participatory processes require substantial time, trained staff, and financial resources which can limit implementation. Therefore, the low resources currently afforded to CDEM Groups suggest that the current system may not be optimal for the resilience of remote communities in New Zealand.

4.8 Acknowledgements

This study was funded by the *Resilience to Nature's Challenges National Science Challenge*, *QuakeCoRE*, and the *Earthquake Commission* (*EQC*). *Project AF8* provided the base scenario for this work. Dr Tom Robinson provided landslide susceptibility modelling outputs used in defining potential impacts to infrastructure. Dr Daniel Blake, Dr Tom Robinson and Kat Hore aided workshop facilitation. We thank these contributions. Most importantly, the authors are extremely grateful to and wish to thank the willing Franz Josef community members, practitioners and local government policymakers who generously gave their time and input.

4.9 References

Ackerman, J 2004, 'Co-governance for accountability: beyond “exit” and “voice”', *World Development,* vol. 32, no. 3, pp. 447-463.

Alcamo, J 2008, 'Chapter six the SAS approach: combining qualitative and quantitative knowledge in environmental scenarios', *Developments in integrated environmental assessment,* vol. 2, pp. 123-150.

Alexander, D 1999, 'The content of emergency training programs', in, Consiglio Nazionale delle Ricerche.

Alexander, D 2000, 'Scenario methodology for teaching principles of emergency management', *Disaster Prevention and Management: An International Journal,* vol. 9, no. 2, pp. 89-97.

Aoki, N 2018, 'Sequencing and combining participation in urban planning: The case of tsunami-ravaged Onagawa Town, Japan', *Cities,* vol. 72, pp. 226-236.

Arnstein, SR 1969, 'A ladder of citizen participation', *Journal of the American Institute of planners,* vol. 35, no. 4, pp. 216-224.

Baker, JW 2008, *An Introduction to Probabilistic Seismic Hazard Analysis (PSHA)*, viewed 09/06/19, https://web.stanford.edu/~bakerjw/Publications/Baker_(2008)_Intro_to_PSHA_v1_3.pdf.

Barnes, PM, Bostock, HC, Neil, HL, Strachan, LJ & Gosling, M 2013, 'A 2300-Year Paleoearthquake Record of the Southern Alpine Fault and Fiordland Subduction Zone, New Zealand, Based on Stacked Turbidites', *Bulletin of the Seismological Society of America,* vol. 103, no. 4, pp. 2424-2446.

Barth, NC 2013, *A tectono-geomorphic study of the Alpine Fault, New Zealand*, University of Otago, New Zealand.

Beaven, S, Wilson, T, Johnston, L, Johnston, D & Smith, R 2016, 'Role of Boundary Organization after a Disaster: New Zealand’s Natural Hazards Research Platform and the 2010–2011 Canterbury Earthquake Sequence', *Natural Hazards Review,* vol. 18, no. 2.

Becker, J, Saunders, W, Hopkins, L, Wright, K & Kerr, J 2008, 'Pre-event recovery planning for land use in New Zealand: An updated methodology', *GNS Science Report 2008/11*, p. 39.

Bishop, P, Hines, A & Collins, T 2007, 'The current state of scenario development: an overview of techniques', *Foresight,* vol. 9, no. 1, pp. 5-25.

Blackstock, KL, Kelly, GJ & Horsey, BL 2007, 'Developing and applying a framework to evaluate participatory research for sustainability', *Ecological economics,* vol. 60, no. 4, pp. 726-742.

Blake, ES, Landsea, CW, Gibney, EJ & Asheville, N 2011, *The deadliest, costliest, and most intense United States tropical cyclones from 1851 to 2010 (and other frequesntly requested hurricane facts)*, NOAA Technical Memorandum NWS NHC-6, Miami, Florida, USA.

Broad, K, Pfaff, A, Taddei, R, Sankarasubramanian, A, Lall, U & de Souza Filho, FdA 2007, 'Climate, stream flow prediction and water management in northeast Brazil: societal trends and forecast value', *Climatic Change,* vol. 84, no. 2, pp. 217-239.

Burton, P, Goodlad, R, Croft, J, Abbott, J, Hastings, A, Macdonald, G & Slater, T 2004, *What works in community involvement in area-based initiatives? A systematic review of the literature*, Home Office Online Report 53, UK, 4.

Butler, JRA, Bohensky, EL, Suadnya, W, Yanuartati, Y, Handayani, T, Habibi, P, Puspadi, K, Skewes, TD, Wise, RM, Suharto, I, Park, SE & Sutaryono, Y 2016, 'Scenario planning to leap-frog the Sustainable Development Goals: An adaptation pathways approach', *Climate Risk Management,* vol. 12, pp. 83-99.

Cannon, T 2014, *'Why do we pretend there is 'Community'? Problems of community based-adaptation (CBA) and community based disaster risk reduction (CBDRR)', IDS Povertics, Institute of Development Studies (UK)*, viewed 27/07/18, http://vulnerabilityandpoverty.blogspot.com/2014/04/why-do-we-pretend-there-is-community.html.

Cash, DW, Clark, WC, Alcock, F, Dickson, NM, Eckley, N, Guston, DH, Jäger, J & Mitchell, RB 2003, 'Knowledge systems for sustainable development', *Proceedings of the national academy of sciences,* vol. 100, no. 14, pp. 8086-8091.

CDEM Act 2002, Civil Defence Emergency Management Act 2002. New Zealand Government.

Centre for Advanced Engineering 1997, *Risks & Realities: A Multi-disciplinary Approach to the Vulnerability of Lifelines to Natural Hazards*, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand.

Chang, SE, McDaniels, T, Fox, J, Dhariwal, R & Longstaff, H 2014, 'Toward disaster-resilient cities: characterizing resilience of infrastructure systems with expert judgments', *Risk Analysis,* vol. 34, no. 3, pp. 416-434.

Cochran, U, Clark, K, Howarth, J, Biasi, G, Langridge, R, Villamor, P, Berryman, K & Vandergoes, M 2017, 'A plate boundary earthquake record from a wetland adjacent to the Alpine fault in New Zealand refines hazard estimates', *Earth and Planetary Science Letters,* vol. 464, pp. 175-188.

Cooke, B 2004, 'Rules of thumb for participatory change agents', *Participation: From tyranny to transformation*, pp. 42-55.

Cooke, B & Kothari, U 2001, *Participation: The new tyranny?*, ZED books, London and New York.

Cutter, SL 1996, 'Vulnerability to environmental hazards', *Progress in Human Geography,* vol. 20, no. 4, pp. 529-539.

Davies, T 2015, 'Developing resilience to naturally triggered disasters', *Environment Systems and Decisions,* vol. 35, no. 2, pp. 237-251.

Davies, T, Beaven, S, Conradson, D, Densmore, A, Gaillard, J, Johnston, D, Milledge, D, Oven, K, Petley, D & Rigg, J 2015, 'Towards disaster resilience: A scenario-based approach to co-producing and integrating hazard and risk knowledge', *International Journal of Disaster Risk Reduction,* vol. 13, pp. 242-247.

Day, TJ 2003, 'Practical Steps in Ensuring Good Risk Communication in a Regional Council', in J Gough (ed.) *Sharing The Future: Risk Communication in Practice,* Centre for Advanced Engineering, Christchurch, pp. 105-116.

de Andrade, MMN & Szlafsztein, CF 2015, 'Community participation in flood mapping in the Amazon through interdisciplinary methods', *Natural Hazards,* vol. 78, no. 3, pp. 1491-1500.

De Pascale, G & Langridge, R 2012, 'New on-fault evidence for a great earthquake in AD 1717, central Alpine fault, New Zealand', *Geology,* vol. 40, no. 9, pp. 791-794.

Deligne, NI, Blake, DM, A.J., D, Grace, ES, Hayes, J, Potter, S, Stewart, C, Wilson, G & Wilson, TM 2015, 'Economics of Resilient Infrastructure Auckland Volcanic Field Scenario', *ERI Research Report,* vol. 2015, no. 3, p. 151.

Dellow, S, Massey, C, Cox, S, Archibald, G, Begg, J, Bruce, Z, Carey, J, Davidson, J, Della Pasqua, F & Glassey, P 2017, 'Landslides caused by the Mw7. 8 Kaikōura earthquake and the immediate response', *Bulletin of the New Zealand Society for Earthquake Engineering,* vol. 50, no. 2, pp. 106-116.

DeWeerd, HA 1967, *Political-military scenarios*, RAND CORP, Santa Monica, California, USA.

Díez, MA, Etxano, I & Garmendia, E 2015, 'Evaluating participatory processes in conservation policy and governance: lessons from a Natura 2000 pilot case study', *Environmental Policy and Governance,* vol. 25, no. 2, pp. 125-138.

DPMC 2016, *National Exercise Programme brochure*, viewed 6/10/18, https://www.dpmc.govt.nz/sites/default/files/2017-03/nep-brochure-web-may2016.pdf.

Duinker, PN & Greig, LA 2007, 'Scenario analysis in environmental impact assessment: Improving explorations of the future', *Environmental Impact Assessment Review,* vol. 27, no. 3, pp. 206-219.

Eiser, JR, Bostrom, A, Burton, I, Johnston, DM, McClure, J, Paton, D, Van Der Pligt, J & White, MPJIJoDRR 2012, 'Risk interpretation and action: A conceptual framework for responses to natural hazards', vol. 1, pp. 5-16.

Ellemor, H 2005, 'Reconsidering emergency management and indigenous communities in Australia', *Global Environmental Change Part B: Environmental Hazards,* vol. 6, no. 1, pp. 1-7.

Espiner, S & Becken, S 2014, 'Tourist towns on the edge: Conceptualising vulnerability and resilience in a protected area tourism system', *Journal of Sustainable Tourism,* vol. 22, no. 4, pp. 646-665.

FEMA 2018, *National Exercise Program*, viewed 10/12/18, https://www.fema.gov/national-exercise-program.

Fenwick, A 2012, *The Value of Lifeline Seismic Risk Mitigation in Christchurch: Summary Report, June 2012*, New Zealand Lifelines.

Fiji Bureau of Statistics n.d., *Government of Fiji: Regional population mapping*, viewed 5/10/18, https://www.statsfiji.gov.fj/index.php/population-gis-maps.

Fischer, F 2000, *Citizens, experts, and the environment: The politics of local knowledge*, Duke University Press.

Fung, A 2006, 'Varieties of participation in complex governance', *Public administration review,* vol. 66, no. s1, pp. 66-75.

Gaillard, J-C & Mercer, J 2013, 'From knowledge to action: Bridging gaps in disaster risk reduction', *Progress in human geography,* vol. 37, no. 1, pp. 93-114.

Gardner, JS 2015, 'Risk complexity and governance in mountain environments', in FP Urbano (ed.), *Risk governance: The Articulation of Hazard, Politics and Ecology*, Springer, Dordrecht, pp. 349-371.

Glacier Country Tourism Group 2018a, *Franz Josef Glacier*, viewed 10/08/2018, http://www.glaciercountry.co.nz/explore-our-regions/glaciers-heritage/franz-josef-glacier-area/.

Glacier Country Tourism Group 2018b, *Glaciers & Heritage*, viewed 10/08/2018, http://www.glaciercountry.co.nz/explore-our-regions/glaciers-heritage/.

Gough, J 2000, ‘Perceptions of risk from natural hazards in two remote New Zealand communities’, *The Australasian Journal of Disaster and Trauma Studies,* vol. 2000-2, p. 15.

Gough, J 2001, ‘Changes in understanding, awareness and preparedness for natural hazard risk in Franz Josef Glacier’, *Institute of Geological and Nuclear Sciences science report 2001/22,* p. 19.

Gough, J, Johnston, D, McSaveney, M, 1999 ‘Community response to natural hazard risk at Franz Josef Glacier’, *Institute of Geological & Nuclear Sciences Limited science report 99/10,* p. 35.

GOV.UK 2014, *Emergency planning and preparedness: exercisies and training*, viewed 10/12/18, https://www.gov.uk/guidance/emergency-planning-and-preparedness-exercises-and-training.

Hagendijk, R & Irwin, A 2006, 'Public deliberation and governance: engaging with science and technology in contemporary Europe', *Minerva,* vol. 44, no. 2, pp. 167-184.

Holzer, JM, Carmon, N & Orenstein, DE 2018, 'A methodology for evaluating transdisciplinary research on coupled socio-ecological systems', *Ecological Indicators,* vol. 85, pp. 808-819.

Howard, TM 2018, 'Balancing the see-saw of natural resource governance: the interaction of legislation, policy and practice in four Australian participatory processes', *Australasian Journal of Environmental Management,* vol. 25, no. 2, pp. 174-192.

James, P, Cairns, G & Wright, G 2015, 'Projecting Alternative Futures', *Urban Sustainability in Theory and Practice: Circles of Sustainability. London: Routledge*, pp. 214-230.

Jenkins, L 2000, 'Selecting scenarios for environmental disaster planning', *European Journal of Operational Research,* vol. 121, no. 2, pp. 275-286.

Johnston, D, Becker, J & Cousins, J 2006, 'Lifelines and urban resilience', *Disaster resilience. Charles C Thomas, Springfield*, pp. 40-65.

Jones, LM & Benthien, M 2011, 'Preparing for a “Big One”: the great southern California ShakeOut', *Earthquake Spectra,* vol. 27, no. 2, pp. 575-595.

Kahn, H & Wiener, AJ 1967, 'The year 2000; a framework for speculation on the next thirty-three years'. Macmillan, New York.

Keeble, BR 1988, 'The Brundtland report:‘Our common future’', *Medicine and War,* vol. 4, no. 1, pp. 17-25.

Kishita, Y, Hara, K, Uwasu, M & Umeda, Y 2016, 'Research needs and challenges faced in supporting scenario design in sustainability science: a literature review', *Sustainability Science,* vol. 11, no. 2, pp. 331-347.

Kok, K, Biggs, RO & Zurek, M 2007, 'Methods for developing multiscale participatory scenarios: insights from southern Africa and Europe', *Ecology and Society,* vol. 12, no. 1, p. 16.

Langridge, R & Beban, J 2011, 'Planning for a safer Franz Josef-Waiau community, Westland District: considering rupture of the Alpine Fault', *GNS Science Consultancy Report,* vol. 217, p. 61.

Langridge, R & Ries, W 2009, 'Mapping and fault rupture avoidance zonation for the Alpine Fault in the West Coast region', *GNS Science Consultancy Report 2009,* vol. 18, p. 47.

Langridge, RM, Buxton, R, Howarth, JD & Ries, WF 2016, *Natural Hazard Assessment for the Township of Franz Josef, Westland District*, GNS Science, Wellington, New Zealand, 2016/33.

Manuel-Navarrete, D, Pelling, M & Redclift, M 2011, 'Critical adaptation to hurricanes in the Mexican Caribbean: development visions, governance structures, and coping strategies', *Global Environmental Change,* vol. 21, no. 1, pp. 249-258.

Maskrey, A 2011, 'Revisiting community-based disaster risk management', *Environmental Hazards,* vol. 10, no. 1, pp. 42-52.

McCahon, I, Elms, D & Dewhirst, R 2006, 'West Coast Engineering Lifelines Group Study: Alpine Fault Earthquake Scenario', p. 204.

McCahon, I, Elms, D & Dewhirst, R 2017, 'Improving Resilience to Natural Disasters. West Coast Lifelines Vulnerability and Interdependency Assessment: Main Report', p. 62.

McDaniels, TL, Chang, SE, Hawkins, D, Chew, G & Longstaff, H 2015, 'Towards disaster-resilient cities: an approach for setting priorities in infrastructure mitigation efforts', *Environment Systems and Decisions,* vol. 35, no. 2, pp. 252-263.

McSaveney, M & Davies, T 1998, 'Natural hazard assessment for the township of Franz Josef Glacier and its environs', *Client Report B,* vol. 43714.

MfE 2018, *Getting involved in council plans and plan preparation processes*, viewed 22/06/2019, https://www.mfe.govt.nz/rma/rma-processes-and-how-get-involved/getting-involved-council-plans-and-plan-preparation-processes.

Millennium Assessment Board 2005, *Millennium Ecosystem Assessment*, Island Press, Washington, DC: New Island.

Mitchell, C 2017, 'Preparing for the big one on the Alpine Fault', *The Press,* viewed, https://www.stuff.co.nz/national/90557913/preparing-for-the-big-one-on-the-alpine-fault.

Mitchell, C & Williams, A 2018, *Thin Ice*, viewed 10/08/18, https://interactives.stuff.co.nz/2018/04/thin-ice/.

Morton, J 2018, *Impact of 1.7m tourists on beautiful NZ*, viewed 10/08/2018, https://www.odt.co.nz/news/national/impact-17m-tourists-beautiful-nz.

Murphy, BL, Anderson, GS, Bowles, R & Cox, RS 2014, 'Planning for disaster resilience in rural, remote, and coastal communities: Moving from thought to action', *Journal of emergency management,* vol. 12, no. 1, p. 16.

Nakicenovic, N, Alcamo, J, Grubler, A, Riahi, K, Roehrl, R, Rogner, H-H & Victor, N 2000, *Special report on emissions scenarios (SRES), a special report of Working Group III of the intergovernmental panel on climate change*, Cambridge University Press.

National Infrastructure Unit 2015, *The Thirty Year New Zealand Infrastructure Plan 2015*, New Zealand Government, Wellington, New Zealand.

Nelson, N & Wright, S 1995, *Power and Participatory Development: Theory and Practice*, ITDG Publishing.

Orchiston, C 2013, 'Tourism business preparedness, resilience and disaster planning in a region of high seismic risk: The case of the Southern Alps, New Zealand', *Current Issues in Tourism,* vol. 16, no. 5, pp. 477-494.

Orchiston, C, Davies, T, Langridge, R, Wilson, TM, Mitchell, J & Hughes, M 2016, *Alpine Fault Magnitude 8 Hazard Scenario*, viewed 8/5/2017, http://projectaf8.co.nz/wordpress/wp-content/uploads/2016/11/project-af8-hazard-model-report-final-october-2016.pdf.

Orchiston, C, Manuel, C, Coomer, M, Becker, J & Johnston, D 2013, 'The 2009 New Zealand West Coast ShakeOut: Improving earthquake preparedness in a region of high seismic risk', *Australasian Journal of Disaster and Trauma Studies,* vol. 2013, no. 2, pp. 56-61.

Orchiston, C, Mitchell, J, Wilson, T, Langridge, R, Davies, T, Bradley, B, Johnston, D, Davies, A, Becker, J & McKay, A 2018, 'Project AF8: developing a coordinated, multi-agency response plan for a future great Alpine Fault earthquake', *New Zealand Journal of Geology and Geophysics*, pp. 1-14.

Oteros-Rozas, E, Martín-López, B, Daw, TM, Bohensky, EL, Butler, JRA, Hill, R, Martin-Ortega, J, Quinlan, A, Ravera, F, Ruiz-Mallén, I, Thyresson, M, Mistry, J, Palomo, I, Peterson, GD, Plieninger, T, Waylen, KA, Beach, DM, Bohnet, IC, Hamann, M, Hanspach, J, Hubacek, K, Lavorel, S & Vilardy, SP 2015, 'Participatory scenario planning in place-based social-ecological research: Insights and experiences from 23 case studies', *Ecology and Society,* vol. 20, no. 4.

Pearce, L 2003, 'Disaster management and community planning, and public participation: how to achieve sustainable hazard mitigation', *Natural hazards,* vol. 28, no. 2-3, pp. 211-228.

Perry, S, Jones, L & Cox, D 2011, 'Developing a scenario for widespread use: best practices, lessons learned', *Earthquake Spectra,* vol. 27, no. 2, pp. 263-272.

Preuss, J & Godfrey, J 2006, *Guidelines for Developing an Earthquake Scenario*, EERI.

Purdie, H, Anderson, B, Chinn, T, Owens, I, Mackintosh, A, Lawson, WJG & Change, P 2014, 'Franz Josef and Fox Glaciers, New Zealand: historic length records', vol. 121, pp. 41-52.

Ratcliffe, J 2000, 'Scenario building: a suitable method for strategic property planning?', *Property management,* vol. 18, no. 2, pp. 127-144.

Ravera, F, Hubacek, K, Reed, M & Tarrasón, D 2011, 'Learning from experiences in adaptive action research: a critical comparison of two case studies applying participatory scenario development and modelling approaches', *Environmental Policy and Governance,* vol. 21, no. 6, pp. 433-453.

Reed, MS 2008, 'Stakeholder participation for environmental management: a literature review', *Biological conservation,* vol. 141, no. 10, pp. 2417-2431.

Reed, MS, Graves, A, Dandy, N, Posthumus, H, Hubacek, K, Morris, J, Prell, C, Quinn, CH & Stringer, LC 2009, 'Who's in and why? A typology of stakeholder analysis methods for natural resource management', *Journal of environmental management,* vol. 90, no. 5, pp. 1933-1949.

Reed, MS, Kenter, J, Bonn, A, Broad, K, Burt, T, Fazey, I, Fraser, E, Hubacek, K, Nainggolan, D & Quinn, C 2013, 'Participatory scenario development for environmental management: A methodological framework illustrated with experience from the UK uplands', *Journal of Environmental Management,* vol. 128, pp. 345-362.

Remling, E & Veitayaki, J 2016, 'Community-based action in Fiji's Gau Island: a model for the Pacific?', *International Journal of Climate Change Strategies and Management,* vol. 8, no. 3, pp. 375-398.

Resource Management Act 1991, New Zealand Government.

Richards, C, Carter, C & Sherlock, K 2004, *Practical approaches to participation*, Socio-Economic Reserach Group (SERG) Policy Brief Number 1, Macaulay Institute.

Riddell, GA, van Delden, H, Dandy, GC, Zecchin, AC & Maier, HR 2018, 'Enhancing the policy relevance of exploratory scenarios: Generic approach and application to disaster risk reduction', *Futures,* vol. 99, pp. 1-15.

Roback, K, Clark, MK, West, AJ, Zekkos, D, Li, G, Gallen, SF, Chamlagain, D & Godt, JW 2018, 'The size, distribution, and mobility of landslides caused by the 2015 Mw7. 8 Gorkha earthquake, Nepal', *Geomorphology,* vol. 301, pp. 121-138.

Robinson, T, Davies, T, Wilson, T & Orchiston, C 2016, 'Coseismic landsliding estimates for an Alpine Fault earthquake and the consequences for erosion of the Southern Alps, New Zealand', *Geomorphology,* vol. 263, pp. 71-86.

Robinson, T, Wilson, TM, Davies, TR, Orchiston, C & Thompson, J 2014, *Design and development of realistic exercise scenarios: a case study of the 2013 Civil Defence exercise Te Ripahapa*, GNS Science, Wellington, New Zealand.

Robinson, TR 2014, *Assessment of coseismic landsliding from an Alpine fault earthquake scenario, New Zealand.* PhD Thesis, Department of Geological Sciences, University of Canterbury, New Zealand.

Robinson, TR, Buxton, R, Wilson, TM, Cousins, WJ & Christophersen, AM 2015, 'Multiple infrastructure failures and restoration estimates from an Alpine Fault earthquake: Capturing modelling information for MERIT', *ERI Research Report,* vol. 2015, no. 4, p. 89.

Robinson, TR, Rosser, NJ, Densmore, AL, Oven, KJ, Shrestha, SN & Guragain, R 2018, 'Use of scenario ensembles for deriving seismic risk', vol. 115, no. 41, pp. E9532-E9541.

Rowe, G & Frewer, LJ 2005, 'A typology of public engagement mechanisms', *Science, technology & human values,* vol. 30, no. 2, pp. 251-290.

SARRAH n.d., *Services for Australian Rural and Remote Allied Health: Defining Remote and Rural Context*, viewed 5/10/18, https://sarrah.org.au/content/defining-remote-and-rural-context.

Saunders, W, Grace, E, Beban, J, Johnston, D 2015, ‘Evaluating Land Use and Emergency Management Plans for Natural Hazards as a Function of Good Governance: A Case Study from New Zealand’, *International Journal of Disaster Risk Science,* vol. 6, pp. 62-74.

Shell International 2003, 'Scenarios: an explorer's guide'. Global Business Environment/Shell International London.

Spangle Associates & Robert Olson Associates 1997, 'The Recovery and Reconstruction Plan of the City of Los Angeles: Evaluation of its Use After the Northridge Earthquake'. Spangle Associates Portola Valley, CA, USA.

Star, SL & Griesemer, JR 1989, 'Institutional ecology,translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39', *Social studies of science,* vol. 19, no. 3, pp. 387-420.

Statistics Canada n.d., *Government of Canada: Data and Definitions*, viewed 5/10/18, https://www150.statcan.gc.ca/n1/pub/21-006-x/2008008/section/s2-eng.htm.

Stats NZ 2013, *2013 Census Quickstats about a place: Franz Josef*, viewed 09/08/2018, http://archive.stats.govt.nz/Census/2013-census/profile-and-summary-reports/quickstats-about-a-place.aspx?request_value=14686&parent_id=14681&tabname=&p=y&printall=true.

Stats NZ 2016, *Tourism Satellite Account: 2016*, viewed, http://archive.stats.govt.nz/browse_for_stats/industry_sectors/Tourism/tourism-satellite-account-2016/summary-results.aspx.

Stats NZ n.d., *New Zealand Government: Defining Urban and Rural*, viewed 5/10/18, http://archive.stats.govt.nz/browse_for_stats/Maps_and_geography/Geographic-areas/urban-rural-profile/defining-urban-rural-nz.aspx.

Stirling, M, McVerry, G, Gerstenberger, M, Litchfield, N, Van Dissen, R, Berryman, K, Barnes, P, Wallace, L, Villamor, P & Langridge, R 2012, 'National seismic hazard model for New Zealand: 2010 update', *Bulletin of the Seismological Society of America,* vol. 102, no. 4, pp. 1514-1542.

Swart, RJ, Raskin, P & Robinson, J 2004, 'The problem of the future: sustainability science and scenario analysis', *Global environmental change,* vol. 14, no. 2, pp. 137-146.

Thompson, MA, Owen, S, Lindsay, J & Leonard, G 2015, *Co-creating solutions: Engaging New Zealand in RNC research. A review of stakeholder engagement and a study of perspectives on co-creating research in NZ*, National Science Challenges: Resilience to Nature's Challenges, Short-Term Project, New Zealand.

Tompkins, EL, Few, R & Brown, K 2008, 'Scenario-based stakeholder engagement: incorporating stakeholders preferences into coastal planning for climate change', *Journal of environmental management,* vol. 88, no. 4, pp. 1580-1592.

Tonkin + Taylor & EY 2017, *Franz Josef Natural Hazards Options Assessment and Cost Benefit Analysis*, Auckland, New Zealand.

UNISDR 2015, *Sendai Framework for Disaster Risk Reduction 2015-2030*, UNISDR, Sendai, Japan.

van der Vegt, RG 2017, 'A literature review on the relationship between risk governance and public engagement in relation to complex environmental issues', *Journal of Risk Research*, pp. 1-18.

Wack, P 1985a, 'Scenarios: Shooting the rapids. Harvard Business Review, v. 63, n. 6'

Wack, P 1985b, 'Scenarios: Uncharted waters ahead', *Harvard Business Review September–October.*

Walz, A, Lardelli, C, Behrendt, H, Grêt-Regamey, A, Lundström, C, Kytzia, S & Bebi, P 2007, 'Participatory scenario analysis for integrated regional modelling', *Landscape and Urban Planning,* vol. 81, no. 1, pp. 114-131.

Webler, T & Tuler, S 2006, 'Four Perspectives on Public Participation Process in Environmental Assessment and Decision Making: Combined Results from 10 Case Studies', *Policy Studies Journal,* vol. 34, no. 4, pp. 699-722.

Wellman, H 1953, 'Data for the study of Recent and late Pleistocene faulting in the South Island of New Zealand', *New Zealand journal of science and technology,* vol. 34, pp. 270-288.

West Coast CDEM Group 2016, *West Coast Civil Defence & Emergency Management Group Plan, Version 2.1*, viewed 10/12/18, https://westcoastemergency.govt.nz/resources/group-plan/.

West Coast Regional Council 2000, *West Coast Regional Policy Statement*, viewed 13/08/2018, https://www.wcrc.govt.nz/Documents/Resource%20Management%20Plans/Resource%20Management%20Plans%20Document%20Library/Regional%20Policy%20Statement/Regional%20Policy%20Statement.pdf.

West Coast Regional Council 2014, 'West Coast Regional Weather Event: Ex Tropical Cyclone Ita, 17 April 2014', p. 30.

Westland District Council 2002, *Westland District Plan*, viewed 21/08/2018, http://district-plan.westland.govt.nz/index.html.

Westland District Council 2012, *Plan Change 7 Information Sheet*, viewed 13/08/2018, https://www.westlanddc.govt.nz/sites/default/files/plan-change-7-information-sheet.pdf.

Westland District Council 2016, *24.11.16 - Council Agenda - Part 1*, viewed 15/08/2018, https://www.westlanddc.govt.nz/sites/default/files/24.11.16%20-%20Council%20Agenda%20-%20Part%201.pdf.

Westland District Council 2017, *Withdrawal of Plan Change 7*, viewed 10/12/18, https://www.westlanddc.govt.nz/withdrawal-proposed-plan-change-7.

Wiggins, JH 1996, 'Letters to the Editor (A reply to 'scientific profiles of the "big one"')', *Natural Hazards Observer (Internet Bulletin),* vol. XX, no. 4

Willis, G 2014, *Managing natural hazard risk in New Zealand - towards more resilient communities*, LGNZ, Wellington, New Zealand.

Wilson, J, Espiner, SR, Stewart, E & Purdie, H 2014, *'Last chance tourism' at the Franz Josef and Fox Glaciers, Westland Tai Poutini National Park: A survey of visitor experience*, Centre for Land, Environment & People, Lincoln University, Lincoln, NZ, LEaP Research Report No. 34.

Wodak, J & Neale, T 2015, 'A critical review of the application of environmental scenario exercises', *Futures,* vol. 73, pp. 176-186.

Wondolleck, JM & Yaffee, SL 2000, *Making collaboration work: Lessons from innovation in natural resource managment*, Island Press.

Wright, G & Cairns, G 2011, *Scenario thinking: Practical approaches to the future*, Springer.

Zorn, C, Davies, AJ, Robinson, TR, Pant, R, Wotherspoon, L & Thacker, S 2018, 'Infrastructure failure propagations and recovery strategies from an Alpine Fault earthquake scenario', *16th European Conference on Earthquake Engineering*, p. 12.

5. Infrastructure failure propagations and recovery strategies from an Alpine Fault earthquake scenario: The value of feedback loops between integrated modelling and participatory processes for disaster impact reduction

Alistair J. Davies[1], Conrad R. Zorn[2], Thomas M. Wilson[1], Liam M. Wotherspoon[3], Sarah Beaven[1], Tim R. H. Davies[1] and Matthew Hughes[1]

[1] University of Canterbury, Christchurch, New Zealand.

[2] University of Oxford, Oxford, United Kingdom.

[3] University of Auckland, Auckland, New Zealand.

Journal: Earthquake Spectra

Submitted: December 2018

5.1 Abstract

While it is well established that community members should participate in resilience planning, participation with genuine decision-making power remains rare. We detail an end-to-end disaster impact reduction modelling framework for infrastructure networks, embedded within a scenario-based participatory approach. Utilising the AF8+ earthquake scenario, we simulate hazard exposure, asset failure and recovery of interdependent critical infrastructure networks. Quantifying service levels temporally offers insights into possible interdependent network performance and community disconnection from national networks, not apparent when studying each infrastructure in isolation. Sequencing participation enables feedbacks between integrated modelling and participants' impact assessments. Shared ownership of modelling outputs advances stakeholders' understanding of resilience measures, allowing real-time implementation, increasing community resilience. Modelling extrapolated national implications from participants' assessments. Readily understood by central government, this format may increase support and resourcing, if nationally significant. Finally, this method tested integrated modelling and impacts assessments, identifying and enabling improvements for both.

5.2 Introduction

Communities require essential services, such as electricity, transport, telecommunications (including calls, texts and data), water and sewerage to be able to function. These essential services are provided by infrastructure networks, such as electricity lines, roads, and fibre optic cables, which are often highly interdependent. Damage to infrastructure, often caused by natural hazards (such as earthquakes), can result in the partial and sometimes complete loss of a given community's essential services for considerable periods of time. The interdependence of infrastructure networks can compound service loss. Impact on one network is likely to have cascading negative consequences for other networks, reducing the service level provided by other networks, and increasing the time required to restore networks (Buldyrev et al., 2010). Accordingly, the modelling of infrastructure networks' asset failure, interdependencies, and recovery are ongoing foci of disaster management research worldwide (Hickford et al., 2018; Ouyang, 2014). However, these models are not well integrated, which can lead to conflicting results (Ouyang, 2014; Saidi et al., 2017). As a result, end-to-end hazard-to-impact-to-recovery modelling for infrastructure networks remains a research gap.

Furthermore, the need for infrastructure resilience is ultimately driven by the need for community disaster resilience (Chang, 2014; Gaillard & Mercer, 2013; National Infrastructure Unit, 2015). It is established that community members should participate in attempts to increase resilience to disasters. Normative reasoning suggests that people have a right to participate in decision-making which affects them, and pragmatic reasoning suggests that participatory processes deliver higher-quality outputs (than those without participation) (Ackerman, 2004; Reed et al., 2013). However, community participation involves substantial time and effort, when all stakeholders have limited time, resources and interest, restricting their capacity to participate in or facilitate additional activities (Reed et al., 2013). For example, existing commitments such as work and family can limit community members' ability to participate, and limited time and resources can similarly discourage project leaders from facilitating intensive participation (Reed et al., 2013). Further, while community members often participate in disaster impact reduction efforts, community participation with genuine decision-making power remains rare and difficult, including in the context of increasing infrastructure resilience (Aoki, 2018; Broad et al., 2007; Cooke & Kothari, 2001).

Chapter 4 introduces a scenario-based participatory approach to enable successful collaboration among community members, researchers, and practitioners, for disaster impact reduction. This approach uses a scenario as a boundary object to enable collaboration between community members, researchers, and practitioners. "Boundary objects" are 'objects which both inhabit several intersecting social worlds *and* satisfy the informational requirements of each of them. Boundary objects are… a means of translation' (Star & Griesemer, 1989, p. 393). Numerous studies have shown that boundary objects can enable successful collaboration between researchers and practitioners, without compromising either group's identity, integrity or autonomy, when all stakeholder groups perceive the boundary object as credible (scientifically and technically accurate), relevant, and legitimate (fairly reflecting stakeholders' divergent views and interests) (Cash et al., 2003; Mauser et al., 2013; Mittelstrass, 2011; Thompson et al., 2015). Accordingly, within disaster impact reduction projects, natural hazard scenarios have proved to be successful boundary objects, enabling knowledge co-production and establishing ongoing relationships (e.g. Centre for Advanced Engineering, 1997; Deligne et al., 2017; Robinson et al., 2014; Spangle Associates & Robert Olson Associates, 1997).

To integrate community members into this established scenario-based approach with genuine decision-making power, Chapter 4 combines and sequences participatory methodologies, following Aoki (2018). Sequencing participation allows different stakeholder groups to participate more intensely at different stages during the overall process, focussing on relevant areas. For example, community members gain more influence assessing how a disaster will impact the community but have lower influence over assessing technical infrastructure restoration times (which infrastructure providers gain more influence over). Sequencing participation also helps to overcome barriers to participation by reducing the time commitment required from each stakeholder group, as discussions of most interest to individual stakeholder groups can be held without requiring all participants. This also helps to constrain and ensure credibility, reducing potential confusion which can be caused by non-experts debating and speculating about the needs and outcomes of parameters they know little about. For example, network infrastructure providers may speculate about community post-disaster needs but may have little specific idea. Equally, community members may guess network restoration times but are unlikely to know these. Combining different participation methodologies can further overcome barriers to participation. Methodologies with a range of participation intensities can be used so that participants who can commit more time are encouraged to, but those who cannot commit the same amount of time can still participate, and do not have to be excluded from the process entirely.

Therefore, in this paper, we aim to:

1) Develop an end-to-end disaster impact reduction modelling framework for infrastructure networks which considers direct and indirect impact, cascading network disruption, network interdependence, and resulting recovery processes; and
2) Embed this framework within a scenario-based participatory approach for disaster impact reduction to:
    i. Advance cross-sector understandings of the implications of disruption to, and recovery strategies for, infrastructure networks;
    ii. Increase the effectiveness and shared ownership of disaster impact reduction efforts; and consequently,
    iii. Increase community resilience to future hazard events.

Notably, this approach couples hazard models (ground shaking, landslides) with the modelling of failure, disruption and recovery across national-scale interdependent networks. Combining this integrated modelling with community- and practitioner-elicited recovery priorities creates feedback loops. These iteratively highlight vulnerabilities, areas to be revised, and new areas to be considered, in the integrated modelling and in practice. Further, the integration of community members and practitioners allows greater understanding, ownership, and ultimately application of this research, thus increasing community resilience.

Accordingly, we aim to answer the following research questions:

1) What is required to integrate hazard and infrastructure modelling, including direct and indirect impacts, cascading network disruption, network interdependence, and resulting recovery processes, to provide end-to-end impact assessment for infrastructure networks?
2) What value is gained by developing an end-to-end model for infrastructure networks?
3) How might a scenario-based participatory approach incorporate an end-to-end impact assessment model to advance both infrastructure and community resilience in an integrated way?
4) What is required to ensure that such scenario-based participatory approaches incorporate ongoing participant outputs to ensure that disaster impact reduction efforts continue to iteratively build on improvements in shared understanding?

5.2.1 The AF8+ scenario

Recent earthquake disasters in New Zealand (2010-11 Canterbury Earthquake Sequence, 2016 "Kaikōura" Earthquake) have demonstrated the potential fragility and interdependence of infrastructure networks, the extent to which communities depend upon infrastructure networks, and the value of pre-event infrastructure resilience efforts (Chapter 3; Fenwick, 2012; McLean et al., 2012). These lessons have informed a strong national drive to increase the resilience of infrastructure networks, which has included the creation of a New Zealand Thirty Year Infrastructure Plan (National Infrastructure Unit, 2015). Under the *Civil Defence Emergency Management Act 2002*

(MCDEM, 2002), New Zealand government agencies at local, regional and national levels, infrastructure providers (often termed "lifeline utilities") and emergency services all have defined functions and responsibilities for disaster readiness, reduction, response, and recovery. Section 60, for example, requires every lifeline utility to be 'able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency' (MCDEM, 2002, p. 40). Lifeline utilities must also establish planning and operational relationships with their regional Civil Defence & Emergency Management (CDEM) Group under the Act. In most regions, lifeline utilities predominantly fulfil their duties under the act by participating in regional lifelines groups, with national representation and coordination undertaken by the New Zealand Lifelines Council (est. 1999). Regional lifelines groups frequently undertake regional-scale vulnerability studies (e.g. AELG, 2014; McCahon et al., 2017; ORC, 2014), post-event debriefs (e.g. Fenwick, 2012; Hamilton & Hinton, 2017; West Coast Regional Council, 2014), and other work fostered or contributed to by the Groups, such as annual emergency management exercises at national, regional, and local scales (DPMC, 2016), and numerous centrally-funded research initiatives which have streams dedicated to researching natural hazard impacts on infrastructure (including the *Resilience to Natures Challenges,* resiliencechallenge.nz; *NZ Centre for Earthquake Resilience*, *QuakeCoRE,* quakecore.nz; *Economics of Resilient Infrastructure,* naturalhazards.org.nz; *DEtermining VOlcanic Risk in Auckland, DEVORA,* devora.org.nz; and *East Coast LAB,* eastcoastlab.org.nz). This work often develops valuable inter-personal and inter-corporate relationships and has improved resilience (e.g. Chapter 3; Fenwick, 2012). However, there has been growing recognition that greater community involvement in infrastructure resilience planning is required, both from domestic experience and international research (Chang, 2014; Gaillard & Mercer, 2013; National Infrastructure Unit, 2015).

The Alpine Fault (South Island, New Zealand) is an earthquake source capable of producing impacts of national significance. The Fault forms the onshore boundary between the Pacific and Australian tectonic plates, accommodating the majority of plate relative motion, up to 28 mm/year (Barth et al., 2014; Biasi et al., 2015; Sutherland et al., 2006). The Alpine Fault generates M_w8+ earthquakes several times per millennium and is late in its current seismic cycle, with an estimated ~30% probability of a major rupture in the next 50 years (Barnes et al., 2013; Cochran et al., 2017; De Pascale & Langridge, 2012; Stirling et al., 2012).

The Alpine Fault was considered a sufficient potential risk that *Project AF8* (projectaf8.co.nz) was commenced in 2016, to undertake detailed planning for future major South Island earthquakes. Focussing on a 7-day **A**lpine **F**ault magnitude **8** earthquake scenario based on decades of prior research activity (Orchiston et al., 2016), *Project AF8* ran six regional and one national response planning workshops, aiming to integrate regional and national planning. In total, more than 500 participants attended these workshops, including emergency managers, policymakers, lifeline utilities, and community representatives, amongst others (Orchiston et al., 2018). The intended outcome is the South Island Alpine Fault Emergency Response (SAFER) framework, focussed on identifying likely impacts and addressing these through strategic planning and coordination activities.

This study builds on the initial *Project AF8* scenario, using an up-scaled scenario that considers the 10 years following the initial earthquake, introduced by Chapter 4, termed the “AF8+ scenario”. The AF8+ scenario allows a shift in focus from reactive short-term response to analyses of longer-term recovery, and was designed as part of a participatory process, according to project goals established by community members in Franz Josef, South Island, New Zealand, and subsequent discussions with practitioners (Chapter 4). Herein, we present findings based on the AF8+ scenario, informed by findings from workshops which enabled engagement between researchers, infrastructure stakeholders, disaster managers, and community members (Chapter 4).

This paper details expected societal disruptions due to infrastructure damages up to 180 days (6 months) following the initial AF8+ event, including those caused by the aftershock sequence and resultant landslides. We seek to address:

1) the location(s) most vulnerable to infrastructure losses for extended periods of time;
2) the magnitude and spatial extent to which disruptions spread due to the interconnected and interdependent nature of the South Island infrastructure networks; and
3) temporal changes in infrastructure network functionality during the recovery process, up to 180 days.

5.3 Methodology

5.3.1 Integrated disaster impact reduction modelling framework for infrastructure networks

Our framework for simulating the cascading network disruption and recovery processes following major hazard-induced damage to interdependent infrastructure networks is presented in the grey boxes in Figure 45. The framework comprises five components: *A: Infrastructure model*, *B: Hazard scenario*, *C: Failure propagation*, *D: Disruption metrics*, and *E: Recovery*. Each of these components is briefly outlined below.

In the first component, *A: Infrastructure model*, spatial infrastructure asset data are assembled to produce functional and topological geospatial network models where networks are represented as graphs of nodes and edges representing discrete single point assets (such as water pumping stations or reservoirs) and connections (such as pipelines between these nodes), respectively. The functionalities of the nodes are identified as: (1) sources - where infrastructure resources or services are generated (e.g. power plants, water supply abstraction points, bulk petroleum storage tanks); and (2) sinks - which signify the final points of delivery of the infrastructure services typically to the customer (e.g. low voltage electricity substations, water pump stations, retail petrol stations). This allows creation of functional pathways, which emerge from the traceability of source-sink connectivity paths both within and between networks that exchange infrastructure resources and services. User demands are allocated to each individual source and sink node based on “business as usual” statistics adopted from asset owner/operator-provided statistics, publicly available reported statistics, or spatial distribution/collection zones intersected with census data to provide an estimate of populations dependent on assets. These user demands are distributed along the functional pathways to create weighted flow network representations. Using these network models, initial asset failures or disruptions are assumed based on the network assets' intersection with the modelled hazard extents in *B: Hazard Scenario*. Such approaches are established within the literature (e.g. Alexander, 2000; Robinson et al., 2014) and have been used in a range of infrastructure risk and vulnerability studies globally (Ouyang, 2014) including studies of interdependent infrastructure vulnerability assessment for New Zealand (Zorn et al., in review-a; Zorn et al., in review-b).

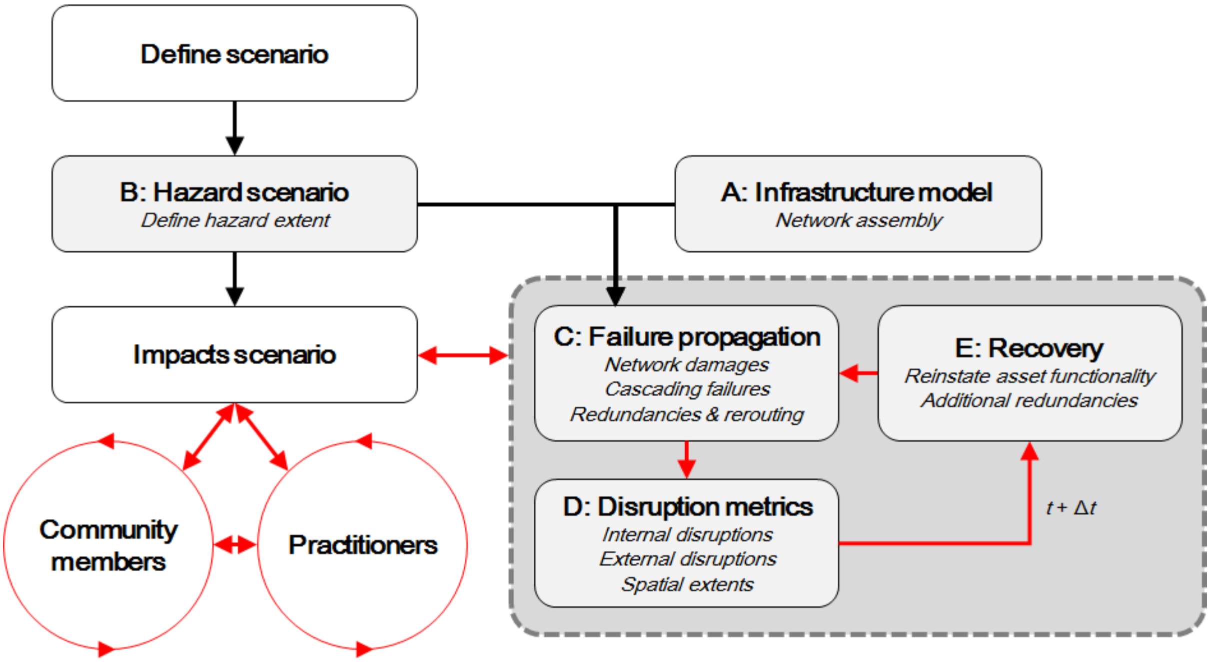

Figure 45. Conceptual diagram of the integrated disaster impact reduction modelling framework for infrastructure networks (indicated by light grey boxes) embedded within the Chapter 4 scenario-based participatory approach. The dashed, dark grey box indicates the iterative process incorporating recovery. Feedback loops are highlighted using red arrows.

Components *C*, *D*, and *E* (Figure 45) then follow an iterative process for each modelled timestep, forming a feedback loop. First, *C: Failure Propagation* enables the propagation of network failures both within a network and between networks where dependency connections are broken and no redundancy or rerouting of service flows are possible within our modelled network configuration. *D: Disruption Metrics* then computes various consequence metrics. We define *Direct Disruptions* as the population/number of users adversely affected due to failed assets within the same network, such as a damaged water treatment plant causing a reduction (or removal) of water provision to downstream customers. By contrast, *Indirect Disruptions* result from failures which are initiated beyond the specific network of interest due to functional dependencies on other networks, such as an undamaged water treatment plant unable to function due to a lack of electricity supply. The spatial outage extent is delineated by the intersection of spatial footprints of failed components and dependent user catchments or distribution/reception zones.

Steps *A-D* represent the state of the disrupted infrastructure at a snapshot of time (t). For the next timestep ($t + \Delta t$), the final component, *E: Recovery*, reinstates asset functionality of previously failed assets (where appropriate). This implies that a restoration process or provision of a permanent redundant supply has occurred to provide pre-event service levels.

5.3.2 Integrated disaster impact reduction modelling framework for infrastructure networks embedded within a scenario-based participatory approach

The above integrated disaster impact reduction modelling framework for infrastructure networks was then embedded within the Chapter 4 scenario-based participatory approach, as shown in Figure 45. First, all stakeholders collaborate to define the scenario, to ensure that the scenario is perceived to be relevant by all participating groups (Kishita et al., 2016; Kok et al., 2007; Reed et al., 2013; Swart et al., 2004; Walz et al., 2007). Second, the hazard scenario is developed, as discussed above (Step B in Figure 45). Third, an impacts scenario is co-created through a range of combined and sequenced participatory methodologies (Chapter 4). In this way, the impacts scenario acts as a boundary object between participating groups, creating an ongoing feedback loop. As new information about likely damage, disruption and recovery priorities is provided to the impacts scenario by one stakeholder group, other stakeholder groups are able to incorporate this new information and, if necessary, alter their own damage, disruption and recovery assessments.

The impacts scenario also functions as a boundary object to embed the integrated disaster impact reduction modelling framework for infrastructure networks into the scenario-based participatory approach. As new damage, disruption and recovery assessments are created by participants in workshops, these can be modelled after workshops to show resulting implications for cascading network disruption, network interdependence, and the effect on recovery. This results in a feedback loop between the integrated modelling and ongoing disaster impact reduction work being undertaken by participants. This feedback loop enables the iterative integration of modelling outputs within the impacts scenario and as a result, this information can be understood and immediately used by community members and practitioners.

5.4 Application

In this section, we briefly summarise the application of the scenario-based participatory approach to the AF8+ scenario, as detailed by Chapter 4. We then step through and expand on the application of each of the modelling framework components (Figure 45) to the AF8+ scenario.

5.4.1 The scenario-based participatory approach to the AF8+ scenario

Project goals were established by Franz Josef community members, and then by practitioners, who asked researchers to facilitate a participatory project to increase disaster resilience (Chapter 4). Subsequently, the AF8+ hazard event scenario (Section 5.4.3; B) was designed and built by researchers in line with these project goals. The impacts scenario was then co-created through a series of participatory workshops. Participation was sequenced, so that separate workshops were held with community members and infrastructure providers before a final "combined" workshop (Figure 46).

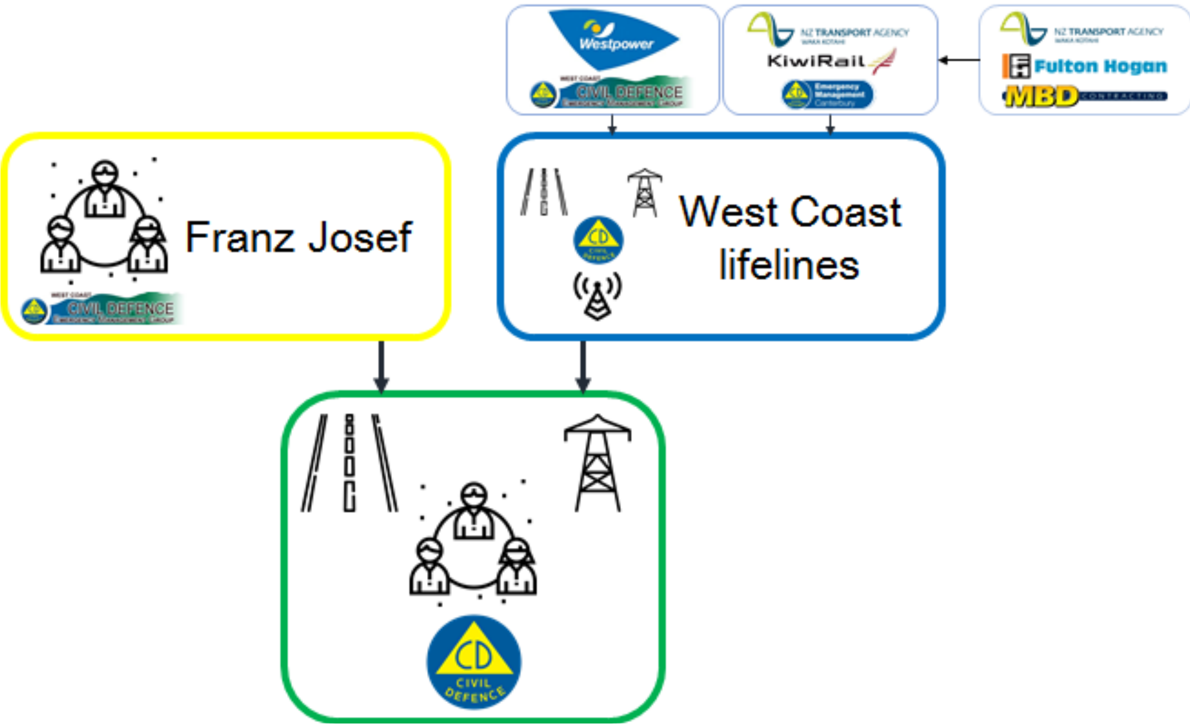

Figure 46. Schematic of the Franz Josef natural hazards scenario-based participatory workshops (each solid box represents a workshop). Separate workshops were held with Franz Josef community members, Westpower, ground transport operators (the New Zealand Transport Agency and KiwiRail) and road contractors (NZ Transport Agency, Fulton Hogan, MBD Construction), and the West Coast lifelines committee. CDEM representatives participated in all workshops, followed by a "combined" workshop (Chapter 4).

In each workshop, the hazard scenario, exposure maps and the impacts scenario to date were presented. The impacts scenario was then co-created. Community members focussed on Franz Josef and practitioners focussed on their infrastructure networks, in the respective workshops. Outputs from the previous workshops and the most recent combined infrastructure modelling were available in subsequent workshops, allowing each workshop to build on the impacts scenario to date (Chapter 4).

5.4.2 Infrastructure model (A)

We adopt the spatial infrastructure asset data and functional network models of Zorn et al. (2018a; 2018b) across the energy (electricity, petroleum), transportation (road, air, ferry, rail), water & waste (water supply, wastewater, solid waste), and telecommunications sectors (mobile), with the addition of a further wired telecommunications network. In each of these models, major assets are represented. Table 7 provides an outline of the node/edge representations for each of the studied networks across the South Island and Figure 47a presents the combined spatial distribution of assets for all networks with respect to mapped faults. For visual clarity, we have not represented each infrastructure sector separately.

User demands are allocated to each of the individual nodes and edges presented in Figure 47 using statistics adopted from asset owner/operator-provided statistics, publicly available reported statistics, or spatial distribution/collection zones, intersected with the smallest publicly available census area unit (~100 permanent residents each). For this paper, we consider residential and passenger transportation modes only (i.e. freight, and commercial and industrial customers dependent on these networks, are not included). The dependencies represented within the network models are provided in Figure 48 (as per Zorn et al., in review-b). It should be noted that these are assumed for normal network connectivity and are assumed to be consistent throughout any recovery processes. Where specific connectivity pairs are unknown, edges are assumed to the closest appropriate asset either geographically or through a shortest path connection route.

Table 7. Network asset representations as nodes and edges with counted values representing the number of exposed assets in this scenario based on the national models of Zorn et al. (in review-a); Zorn et al. (in review-b).

Infrastructure sector	**Network**	**Asset representation**	
		Node	**Edge**
Energy	Electricity	63 generation sources, 48 transmission and 289 distribution substations	Transmission and sub-transmission power lines
	Petroleum	5 bulk storage facilities, 431 retail petroleum stations	Connected via state highway Network
Telecommunications	Wired	322 exchanges, 2313 cabinets	Fibre and copper connections
	Wireless	1053 mobile transmitter towers	Connectivity to wired network
Water & Waste	Water supply	585 source, treatment, pumping, or storage nodes	Major transmission or distribution pipelines
	Wastewater collection	354 pump station or treatment assets	Major collection pipelines
	Solid waste	239 collection, transfer, or landfill assets	Routed via state highway network
Transportation	State highway (SH)	855 bridges/tunnels	State highway classified roads
	Rail	16 stations	Rail tracks
	Air	13 airports	Flight routes (41 domestic, 4 international)
	Ferry	13 ferry terminals	Ferry routes (10)

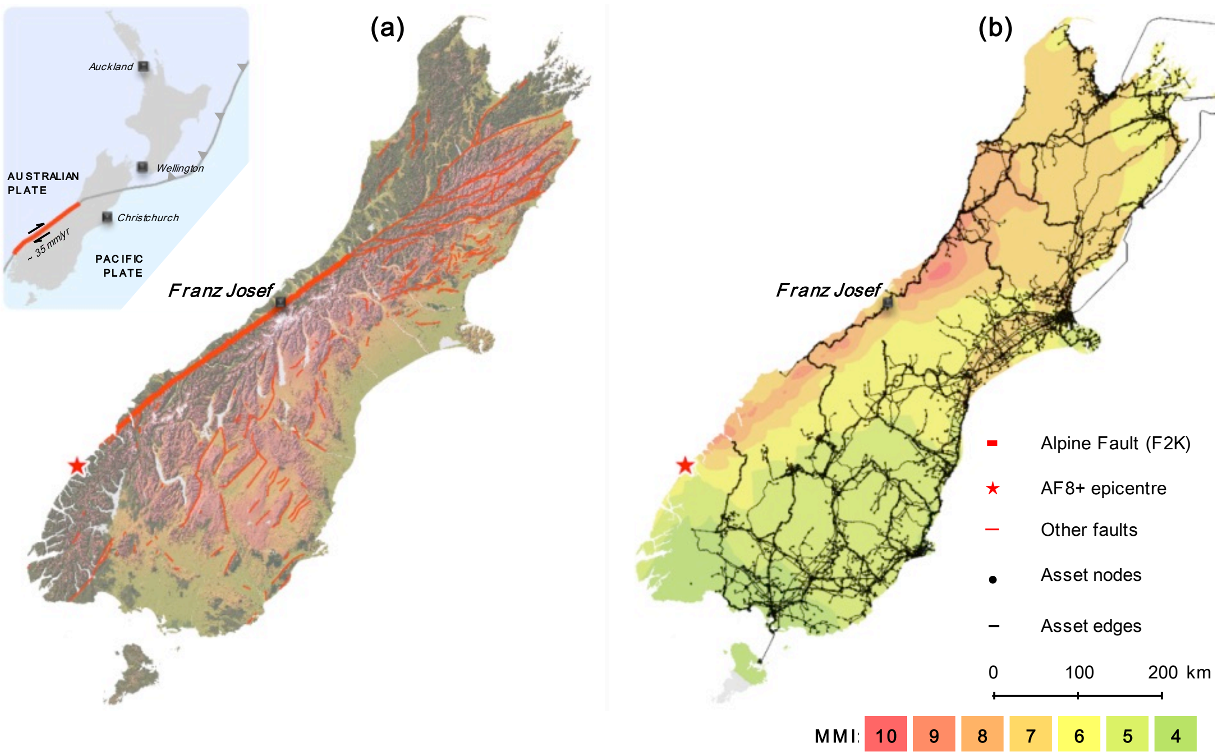

Figure 47. (a) South Island faults, including the F2K section of the Alpine Fault, and (b) spatial distribution of studied infrastructures with respect to MMI shaking intensities used in the AF8+ scenario, converted from Bradley et al. (2017). Inset map shows plate tectonic context of New Zealand and the Alpine Fault.

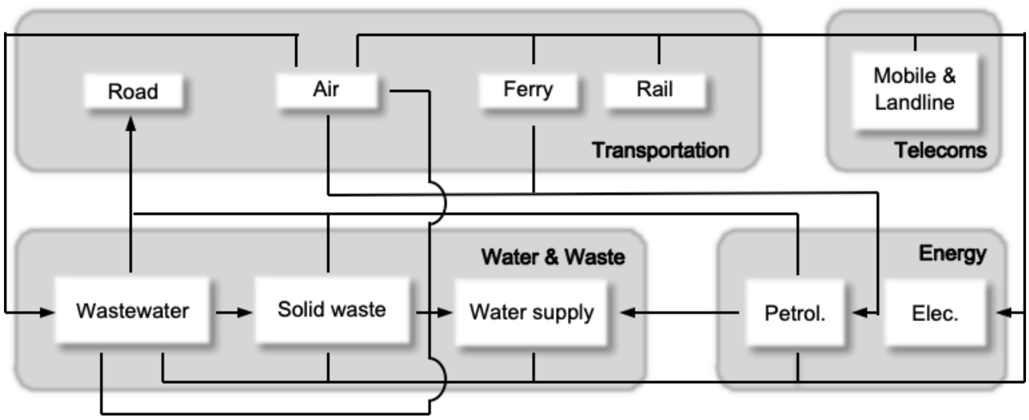

Figure 48. Simplified representation of the directed dependencies modelled from Zorn et al. (in review-b). An infrastructure i reliance on infrastructure j is represented as i→j.

5.4.3 Hazard scenario (B)

The AF8+ scenario adopts a northeast-directed 411 km rupture of the Alpine Fault between Fiordland and Lake Kaniere (F2K) with corresponding ground shaking determined by Bradley et al. (2017) (Figure 47). While this aspect of the scenario is considered highly uncertain by the *Project AF8* science team, it was adopted given the frequency of reverse-slip earthquakes at the southern end of the Alpine Fault in recent decades (Barnes et al., 2013) progressing from a SW to NE direction (Downes & Dowrick, 2014; McGinty, 2001) and because it produces stronger ground shaking in populated areas on the west and east coasts than comparable scenarios (Orchiston et al., 2016; Orchiston et al., 2018). Chapter 4 extended the scenario from 7 days to 10 years (herein we focus on the first 180 days) and reduced some additional hazard severities that were previously heightened to emphasise the emergency response focus (e.g. replacement of a 1-in-100 year rainstorm on Day 3 with historic rainfall data and an updated aftershock sequence). Co-seismic landslide exposure was determined through the approach of Robinson et al. (2016). Earthquake rupture, earthquake shaking, rockfall exposure and landslide reactivations were determined through expert judgement.

5.4.4 Failure propagation (C)

Each individual network asset is assigned one of three initial functionality states as a direct result of the shaking and landslide models described above. These correspond to i) complete disruption, ii) some interim level of functionality, or iii) no disruption such that normal pre-event service is provided.

Disruptions were derived from locations where assets intersected the AF8+ scenario modelled fault rupture, shaking intensities (using Modified Mercalli Intensities (MMI), see Figure 47b), and landslide runout footprints, with infrastructure stakeholders providing further input regarding local geology, asset vulnerability, and likely impacts on the assets, based on recent experiences. Expected recovery times were also derived. In applying these failures, where alternative source-sink connectivity paths do not exist, all dependent nodes/edges are assumed to be disrupted. To reduce data requirements and model complexities, we assume no capacity constraints at network edges and nodes, and we make further assumptions based on expert advice regarding reliabilities of supply (or levels of service) provided by specific networks following an AF8+ style scenario. For example, electricity supply networks could be expected to provide intermittent service to end-users given the potential for power cuts following an earthquake due to aftershocks and voluntary disconnections for inspection or repair. In such cases, the interim level of functionality is assumed.

5.4.5 Disruption metrics (D)

The consequence of asset failure is quantified based on the total user disruptions after allowing for redundancies and rerouting. Under full disruptions, all dependent users are considered disrupted. Under partial disruption, half of the additional affected users are considered disrupted. Further, for some network functions (namely solid waste movements, wastewater solids disposal to landfills, and petroleum delivery to retail outlets), if rerouting is required, potential user disruptions are assumed to be a function of the increase in travel distance as per Zorn et al. (in review-b).

Disruptions are defined as being either initiated by *direct* or *indirect* causes (Section 2). Given the wide spatial extent of potential damages throughout the AF8+ scenario, indirect disruptions could be attributed to multiple sources. For example, a retail petrol station can be disrupted for a range of reasons, such as (but not limited to): i) loss in electricity supply such that pumping, payment, and safety measures are inoperable, ii) damage to the bulk supply point at which fuel is distributed, or iii) closure of the road/pipe networks required to transport fuel to the retail stations. If any combination of these occurs, the downstream retail petrol stations will be indirectly disrupted. However, attributing customer disruptions to all the indirectly causing infrastructures would lead to multiple counting. Therefore, we assume a strength (or priority) of dependency for each of the dependencies modelled (Figure 48). In the retail pump station example, besides being directly impacted by the hazard, we consider a loss of electricity supply to cause the most immediate impact and therefore to be the leading, or initiating, infrastructure cause of indirect disruptions. While a functional road network is essential for the ongoing delivery of fuel supply to the retail petrol station, on-site storage means that a temporary road closure would not have the same impact on customers compared to a loss of electricity, and therefore complete inoperability.

5.4.6 Recovery (E)

For this application, due to current data availability, we have focussed on five timesteps: 0-1 days (the initial impacts in the first 24 hours), 3 days, 7 days, 30 days, and 180 days. Individual asset recovery rates were assumed from a range of Alpine Fault studies (Robinson et al., 2014; Robinson et al., 2015) and local vulnerability studies (McCahon et al., 2017). These were updated using preliminary findings from the scenario-based participatory approach (Section 5.4.1), integrating the modelling as shown in Figure 45.

5.5 Results

Franz Josef community members made detailed estimates of the community's post-disaster capacity in the “Franz Josef” workshop (Figure 46). In summary, the community expected Franz Josef to have: 2000 tourists to account for and evacuate; 3 satellite phones; 5 helicopters; 48 hours triage medical supplies; 4 days of food for tourists; 2 weeks of food for residents; 10 days of diesel; and 20 days of petrol.

Network outages over time were subsequently derived from the practitioner and “combined” workshops. West Coast regional electricity outages are shown in Figure 49. South Island state highway outages are shown in Figure 50. South Island rail network outages were also established but are not shown because it was expected that there would be no rail service on the East-West line, including the West Coast, west of Springfield for several years.

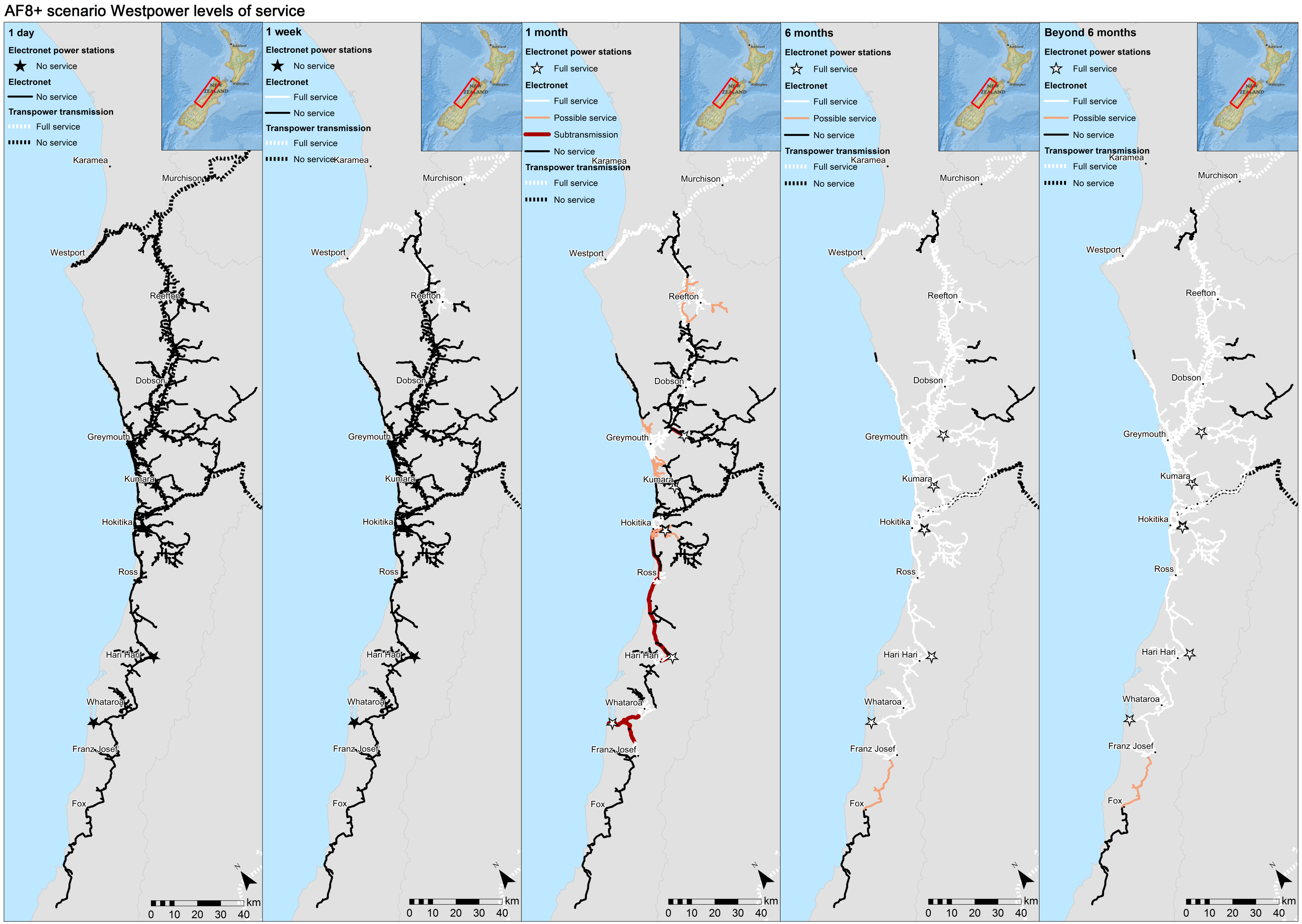

Figure 49. The co-created AF8+ impact scenario for Westpower electricity service levels.

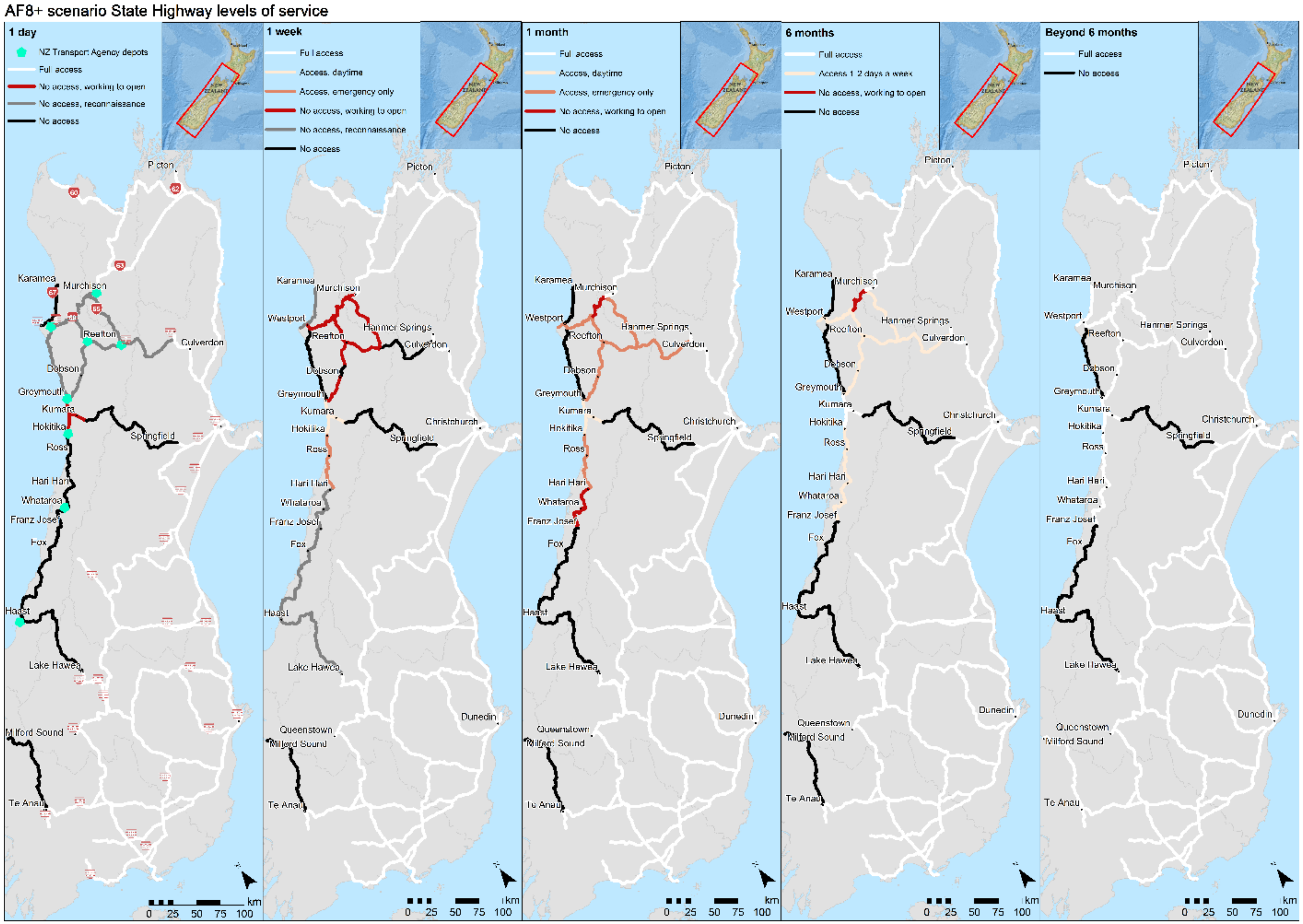

Figure 50. The co-created AF8+ impact maps for South Island state highways' service levels.

The modelled spatial extents of infrastructure network outages over time are shown in Figure 51. Shading indicates the number of infrastructure networks that are providing a complete or interim level of disruption to normal service. Timesteps of 0 and 3 days are combined as some interim level of services are expected to remain over these times, i.e. no complete recovery to pre-event levels is simulated.

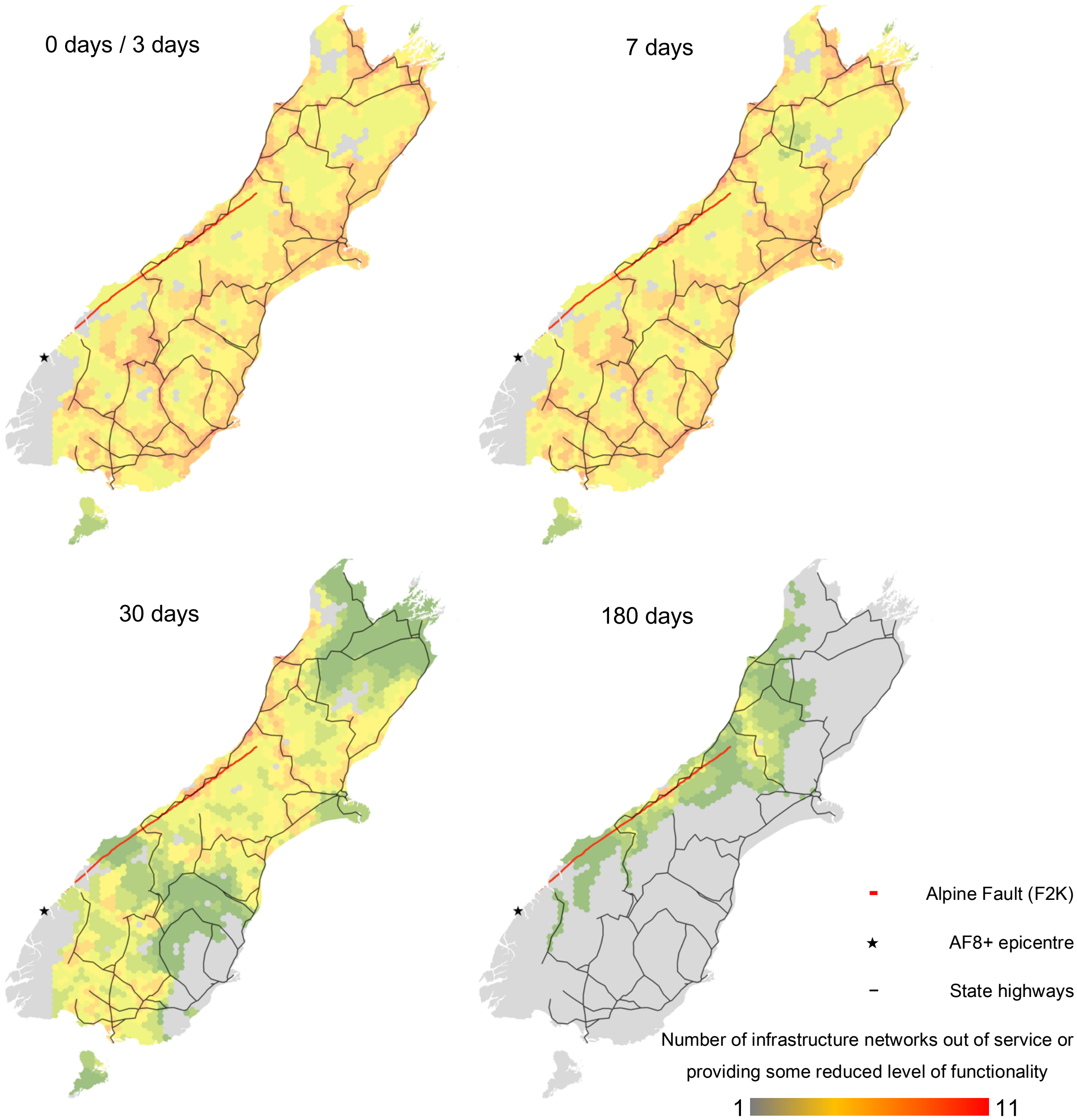

Figure 51. Spatial extents and number of infrastructure disruptions across the South Island. Darker (red) cells indicate a higher proportion of disrupted infrastructure services (either full disruption, or some reduced level of functionality/reliability compared to pre-event services) with greyed out cells representing normal pre-event functionality (or areas without any permanent residents and hence losses in infrastructure service).

Recovery (to full pre-disruption service levels) propagates from the north, east, and south-east after day 7. This is due largely to the more rapid re-instatement of interim/partial levels of service due to available resources (physical and human) located in these areas and less damage to the major assets represented in the models. At the larger timesteps (30 days / 180 days) the West Coast region still shows substantial infrastructure disruptions: either complete or at some interim reduced level of functionality. Much of these disruptions can be attributed to the requirement for alternative source-sink connectivity paths for petroleum delivery, solid waste movement, and sewage disposal, with any deviation from normal pre-event service levels highlighted in Figure 51. Updating model simulations with new network arrangements (i.e. the definition of normal, interim, and no service) should be a focus in future research.

Many infrastructure recovery trajectories correlate closely to electricity network function (Figure 52a). While electricity providers advise the potential for "islanding" of electricity within the West Coast region within 180 days if the national grid is unable to be reconnected (Chapter 4), some locations within the West Coast region may remain without, or with intermittent, electricity supplies. Regardless of location, in this (or any similar) scenario, infrastructures dependent on electricity within the West Coast region should continue to consider potentially widespread use of back-up electricity sources to aid initial recovery.

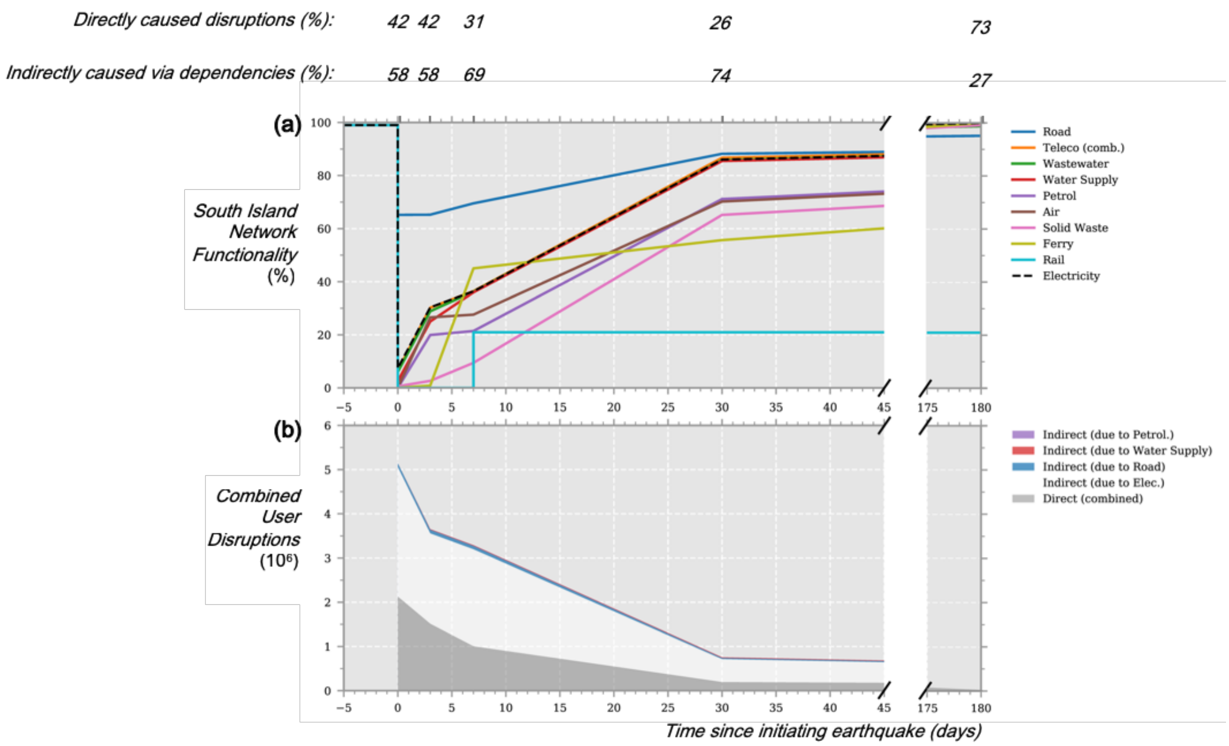

Figure 52. (a) Infrastructure network functionality for the South Island of New Zealand in terms of users disrupted (or passenger-kilometres restored for state highways) and (b) the attribution of disruptions to direct or indirect causes (via interdependencies) combined across networks. A selection of Wellington (ferry/air) and South Island bound transport passengers (air) is also included.

This dependence on electricity is also reflected in Figure 52b, where the majority of user disruptions, across the presented time frame, can be attributed to indirect failures: predominantly disconnections in electricity supply. At $t = 0$, direct damages (combined across all infrastructures) account for 40% of the cumulative user disruptions with 60% externally initiated. With redundant electricity supplies, the proportion of indirect electricity-initiated disruptions would be expected to decrease (particularly for the mobile and wired telecommunications sectors which represent a combined ~2 million potential user disruptions at peak) and/or be reassigned as indirectly-initiated disruptions, due to reduced road, water supply, or petroleum access, amongst others. Explicitly incorporating redundancies and their attributes/dependencies into the modelling framework (e.g. battery life/generator refuelling requirements/road access/supervision) would be a valuable extension to this research and should be incorporated as data for this become available.

5.6 Discussion

We have presented an application of an end-to-end modelling framework for earthquake shaking and landslide hazards coupled with interdependent critical infrastructure network models and the corresponding recovery processes. This integrated modelling immediately highlighted several discussion points for those concerned with reducing the impacts of major South Island disasters. The vulnerability of the West Coast region of the South Island is clear, as are the expected extended recovery times for many dependent infrastructures due to major disconnection from the transportation (predominantly state highway) and electricity networks. Given the mountainous setting and (resulting) financial cost, increasing connectivity (and therefore redundancy) across the state highway network is largely unfeasible. Therefore, improving and/or maintaining asset robustness should be a priority. For electricity, ongoing work by network owner/operators to introduce embedded generation (local generation sources connected to the distribution network reducing the reliance on the national grid) and backup supplies in critical areas within the West Coast region should substantially benefit the local resident populations while aiding timely recovery for dependent infrastructures.

This end-to-end modelling framework was embedded within a scenario-based participatory approach for disaster impact reduction. The scenario-based participatory approach coupled hazard models (ground shaking, landslides) with community- and practitioner-elicited post-disaster capacities and recovery priorities by using a scenario as a boundary object. Sequencing and combining participation methodologies created a feedback loop between community members and practitioners (Chapter 4). For example, community members identified that they would be severely impacted locally, have limited resources and a large population to support, and would be isolated. Practitioners were able to confirm that the community would be inaccessible via ground transportation (i.e. state highways) for months (Figure 50). Subsequently, the community identified that they could self-ration to ensure that supplies would last, and road operators identified that due to the magnitude of regional damage, it would be more beneficial for locally-based road contractors to help repair local infrastructure, including local roads and bridges, water pipes, and sewerage, than attempting to open the state highways, as this would require a structured, centrally-led and resourced response.

Embedding the end-to-end modelling framework within the scenario-based participatory approach had three obvious benefits. First, simulation of failure, disruption and recovery across national-scale interdependent networks allowed community members and practitioners to use the modelled impacts to advance their assessments of likely disruption and recovery strategies. Second, it helped to translate the relative importance of the spatial extents and number of infrastructure network outages (Figure 51) in relation to communities', and particularly Franz Josef's, post-disaster capacities, and so their ability to recover. Third, this method allowed testing of integrated modelling and impacts assessments, as community members and practitioners identified vulnerabilities, enabling appropriate adjustments to modelling and relevant disaster impact reduction measures implemented by community members and practitioners. For example, where the modelling initially highlighted dependence on electricity, practitioners and community members identified dependence on road access and petroleum supplies to be the greatest limiting factor throughout the recovery phase. In short, the modelling highlighted areas requiring increased focus in practice, while practitioners and community members highlighted necessary improvements for models. Road access and petroleum dependence were not accurately represented in the curves of Figure 52, as the dependencies represented in our model highlight the connectivity required for normal operation as opposed to any new or changing dependencies arising to enable recovery. Additionally, the potential indirect disruptions due to petroleum shortages across the West Coast region during the recovery process are not immediately visible in Figure 52b. This is due to the modelling approach that defines user demands based on private car refuelling as opposed to petroleum demands for recovery works. Further supply shortages, for those restoring various infrastructure network functionalities, could substantially change the curves presented in Figure 52a, with the potential for cascading delays across multiple networks.

Moreover, coupling the integrated infrastructure modelling and the scenario-based participatory approach created a valuable feedback loop between the integrated infrastructure modelling and the scenario-based participatory approach (Figure 45), which was enabled by sequencing participation. As new damage, disruption and recovery assessments were identified by workshop participants, they were incorporated into the modelling to show resulting implications for cascading network disruption, network interdependence, and effects on recovery. Community members noted that this feedback loop critically added credibility to their impact assessment by extrapolating the national level implications of the integrated community assessment of local damage, and so be translated into a format which is readily understood by government at a national level. In turn, this increased the likelihood of central support and resourcing for relevant national-level disaster impact reduction efforts for the community. Embedding modelling within the scenario-based participatory approach also increased the shared ownership of the modelling and allowed both community members and practitioners to (in some cases immediately) implement disaster impact reduction measures at the local and regional levels in response to the implications of the modelling (Chapter 4). For example, a Franz Josef business owner noted that "from a business point of view, knowing likely outage times, as shown on the maps used in the workshop [Figure 49; Figure 50], is very useful for crisis management."

Notably, willingness to participate was critical to the success of this process. While lifeline utilities are legislated to improve disaster readiness, reduction, response, and recovery (MCDEM, 2002) (Section 5.2.1), the additional leadership and willingness to participate in this process shown by the West Coast Engineering Lifelines Group, and in particular the New Zealand Transport Agency and Westpower greatly aided this process. Moreover, the drive shown by community members to start the process, and the unwavering commitment of community members to increase the resilience of Franz Josef cannot be understated as essential to the process. This may have been partly enabled by the tight-knit and remote character of this community, as it has been established that place attachment and strong connections between community members (including government employees) can enable compromises for the good of the community (Aoki, 2018; Espiner & Becken, 2014; Orchiston, 2013). This is not to say that participation was easy. The scenario lacked some credibility insofar as national telecommunications and electricity providers/distributors did not engage with the process. This increased the influence of other stakeholders, particularly academics, on the scenario, as best judgement was used as a substitute for participation. Further, while complete participation is a near impossibility for any project of this scale, when key personnel were unable to attend, this affected, and in some instances limited, discussions. Utilising a wider range of participation methodologies beyond exclusively organising workshops could have increased participation in the process. Overall, these difficulties highlight the problems with voluntary collaborative planning.

Several extensions to this work are required both to i) assess the generalised recovery strategies and priorities across a wider range of potential hazard event scenarios that are both in progress and proposed, particularly building on the need to focus on recovery, and not just on the initial response; and ii) to improve the application of the integrated framework in future projects. Firstly, the formal linking of hazard models, such as ground motion (Bradley et al., 2017), landslides (Robinson et al., 2016) and liquefaction (Motha et al., 2017), can provide a range of realistic inputs and allow model updates to be easily included when available. Improvements are further envisaged across each of the infrastructure sector models. In addition to increasing asset data (quality and quantity) and formalising attributes (such as whether assets are buried/overhead and if redundant electricity supplies are present), process-based sector models (i.e. power flow, water supply hydraulics, traffic flow) would be desirable for more accurately modelling user disruptions. In this paper, we have assumed functionality wherever connectivity exists, largely ignoring capacities of assets such as power line properties, pipe diameters, or the number of lanes on a given highway. However, building detailed calibrated network models at a South Island scale proves difficult given the extensive data requirements and inherent computation costs – depending on the desired resolutions. Despite this, a number of these wider infrastructure network process models are in development through the research initiatives discussed in Section 1 (e.g. Liu et al., 2017). Similarly, there is further opportunity to provide a more robust assessment of damage and recovery at local/neighbourhood scales by incorporating the highly detailed water supply network fragility and recovery models of Bellagamba et al. (2018), without the need for extensive hydraulic modelling. Further, population movements (and therefore demands), transportation network behaviours (i.e. origin-destination pairings) and changing dependencies will adjust our definitions of 'normal' service levels. Taking these into account will allow a more accurate representation of the true user disruption as opposed to pre-event comparisons, which are more suitable to lower-intensity events. The temporal resolution of any model updates should also be carefully considered. Finally, while this paper demonstrates that it is possible to integrate hazard and infrastructure modelling today, doing so was challenging. By demonstrating the value of end-to-end modelling, we hope that this will encourage future modelling to be designed to be compatible with integrated modelling frameworks.

This paper has outlined an approach to enable the integration of knowledge between community members, researchers, and practitioners, and has highlighted the benefits of end-to-end disaster modelling and of using a scenario-based participatory approach to integrate this modelling with preparedness assessment. Further, this paper has proved that using a scenario as a boundary object and sequencing participation also enables the integration of autonomous participant initiatives within the scenario-based participatory approach introduced by Chapter 4. This suggests that different autonomous initiatives (in addition to integrated infrastructure modelling) could be integrated by any participating group. Overall, the collaborative linking of scientific, technical, and community knowledge offers great potential to increase resilience of socio-technical systems in preparing for future events such as the anticipated Alpine Fault rupture.

5.7 Conclusions

This paper has addressed its research questions as follows:

1) An end-to-end disaster impact reduction modelling framework for infrastructure networks has been outlined. This integrated direct and indirect impacts, cascading network disruption, network interdependence, and resulting recovery processes.
2) When applied to the AF8+ Alpine Fault earthquake scenario, this integrated modelling immediately highlighted several discussion points for those concerned with reducing the impacts of major South Island disasters, particularly concerning extended recovery times for many dependent infrastructures due to major disconnection from electricity and transportation (predominantly state highway) networks. Improving and/or maintaining asset robustness should be a priority, as should ongoing work to introduce embedded generation and backup supplies in critical areas within the West Coast region.
3) The end-to-end modelling framework was embedded within a scenario-based participatory approach (Chapter 4) by using a scenario as a boundary object and sequencing and combining participatory methodologies (Aoki, 2018; Cash et al., 2003). This created a feedback loop. As community members and practitioners outlined their assessments of likely damage, disruption, and recovery priorities, these were used to advance the modelling, and modelled outputs were then fed back into the participatory approach. This highlighted

vulnerabilities within integrated modelling and impact assessments by community members and practitioners, improving both.

4) Critically, the feedback loop increased the shared ownership of the modelling, consequently allowing both community members and practitioners to (in some cases immediately) implement disaster impact reduction measures due to the implications of the modelling, increasing community resilience to future hazard events. Further, the modelling also translated the integrated community assessment of local damage to national implications, allowing the community assessment to be communicated more clearly to national government, increasing the likelihood of relevant national-level disaster impact reduction policies for the community.

This application particularly highlighted the criticality of sequencing participation to the scenario-based participatory approach. Beyond the genuine two-way communication required to ensure that boundary objects are perceived by all participants to be relevant, credible, and legitimate (Cash et al., 2003), the participatory approach (Chapter 4) benefits from sequencing that enables feedback loops to occur, as assessments iteratively build on the current best shared understanding.

Overall, this approach has been extremely well-received by community members and practitioners, having addressed two key needs: integrated modelling and genuine community participation. The willingness of community members and practitioners to participate was essential to this success. The process would benefit from further validation, evaluation, and numerous improvements (many identified herein), but clearly, future research in this area is likely to be both highly valuable and highly valued.

5.8 Acknowledgements

This study was funded by the Resilience to Nature's Challenges National Science Challenge, QuakeCoRE, and the Earthquake Commission (EQC). Project AF8 provided the base scenario for this work. Dr Thomas Robinson provided landslide susceptibility modelling outputs used in defining potential impacts to infrastructure. Dr Scott Thacker and Dr Raghav Pant provided technical input into the approach used for modelling national scale interdependent infrastructure networks. Dr JC Gaillard aided development of the participatory approach. We thank these contributions. Most importantly, the authors are extremely grateful to and wish to thank the willing Franz Josef community members and practitioners who generously gave their time and input.

5.9 References

Ackerman, J 2004, 'Co-governance for accountability: beyond “exit” and “voice”', *World Development,* vol. 32, no. 3, pp. 447-463.

AELG 2014, *Auckland Engineering Lifelines Project Stage 2: Assessing Auckland’s infrastructure vulnerability to natural and man-made hazards and developing measures to reduce our region’s vulnerability, Version 1.1*, Auckland Engineering Lifelines Group (AELG), Auckland, New Zealand.

Alexander, D 2000, 'Scenario methodology for teaching principles of emergency management', *Disaster Prevention and Management: An International Journal,* vol. 9, no. 2, pp. 89-97.

Aoki, N 2018, 'Sequencing and combining participation in urban planning: The case of tsunami-ravaged Onagawa Town, Japan', *Cities,* vol. 72, pp. 226-236.

Barnes, PM, Bostock, HC, Neil, HL, Strachan, LJ & Gosling, M 2013, 'A 2300-Year Paleoearthquake Record of the Southern Alpine Fault and Fiordland Subduction Zone, New Zealand, Based on Stacked Turbidites', *Bulletin of the Seismological Society of America,* vol. 103, no. 4, pp. 2424-2446.

Barth, N, Kulhanek, D, Beu, A, Murray-Wallace, C, Hayward, B, Mildenhall, D & Lee, DE 2014, 'New c. 270 kyr strike-slip and uplift rates for the southern Alpine Fault and implications for the New Zealand plate boundary', *Journal of Structural Geology,* vol. 64, pp. 39-52.

Bellagamba, X, Bradley, B, Wotherspoon, L & Hughes, M 2018, *Development of fragility functions for buried pipelines based on New Zealand data*, Proceedings of the 16th European Conference on Earthquake Engineering, 18-21 June, Thessaloniki, Greece.

Biasi, GP, Langridge, RM, Berryman, KR, Clark, KJ & Cochran, UA 2015, 'Maximum-likelihood recurrence parameters and conditional probability of a ground-rupturing earthquake on the Southern Alpine Fault, South Island, New Zealand', *Bulletin of the Seismological Society of America,* vol. 105, no. 1, pp. 94-106.

Bradley, BA, Bae, SE, Polak, V, Lee, RL, Thomson, EM & Tarbali, K 2017, 'Ground motion simulations of great earthquakes on the Alpine Fault: effect of hypocentre location and comparison with empirical modelling', *New Zealand Journal of Geology and Geophysics*, pp. 1-11.

Broad, K, Pfaff, A, Taddei, R, Sankarasubramanian, A, Lall, U & de Souza Filho, FdA 2007, 'Climate, stream flow prediction and water management in northeast Brazil: societal trends and forecast value', *Climatic Change,* vol. 84, no. 2, pp. 217-239.

Buldyrev, SV, Parshani, R, Paul, G, Stanley, HE & Havlin, S 2010, 'Catastrophic cascade of failures in interdependent networks', *Nature,* vol. 464, no. 7291, pp. 1025-1028.

Cash, DW, Clark, WC, Alcock, F, Dickson, NM, Eckley, N, Guston, DH, Jäger, J & Mitchell, RB 2003, 'Knowledge systems for sustainable development', *Proceedings of the national academy of sciences,* vol. 100, no. 14, pp. 8086-8091.

Centre for Advanced Engineering 1997, *Risks & Realities: A Multi-disciplinary Approach to the Vulnerability of Lifelines to Natural Hazards*, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand.

Chang, SE 2014, 'Infrastructure resilience to disasters', *The Bridge,* vol. 44, no. 3, pp. 36-41.

Cochran, U, Clark, K, Howarth, J, Biasi, G, Langridge, R, Villamor, P, Berryman, K & Vandergoes, M 2017, 'A plate boundary earthquake record from a wetland adjacent to the Alpine fault in New Zealand refines hazard estimates', *Earth and Planetary Science Letters,* vol. 464, pp. 175-188.

Cooke, B & Kothari, U 2001, *Participation: The new tyranny?*, ZED books, London and New York.

De Pascale, G & Langridge, R 2012, 'New on-fault evidence for a great earthquake in AD 1717, central Alpine fault, New Zealand', *Geology,* vol. 40, no. 9, pp. 791-794.

Deligne, NI, Fitzgerald, RH, Blake, DM, Davies, AJ, Hayes, JL, Stewart, C, Wilson, G, Wilson, TM, Castelino, R & Kennedy, BM 2017, 'Investigating the consequences of urban volcanism using a scenario approach I: Development and application of a hypothetical eruption in the Auckland Volcanic Field, New Zealand', *Journal of Volcanology and Geothermal Research,* vol. 336, pp. 192-208.

Downes, GL & Dowrick, DJ 2014, *Atlas of Isoseismal Maps of New Zealand Earthquakes, 1843–2003, Second Ed.*, Institute of Geological & Nuclear Sciences, Monograph 25 (issued as a CD), Institute of Geological & Nuclear Sciences, Lower Hutt, New Zealand.

DPMC 2016, *National Exercise Programme brochure*, viewed 6/10/18, https://www.dpmc.govt.nz/sites/default/files/2017-03/nep-brochure-web-may2016.pdf.

Espiner, S & Becken, S 2014, 'Tourist towns on the edge: Conceptualising vulnerability and resilience in a protected area tourism system', *Journal of Sustainable Tourism,* vol. 22, no. 4, pp. 646-665.

Fenwick, A 2012, *The Value of Lifeline Seismic Risk Mitigation in Christchurch: Summary Report, June 2012*, New Zealand Lifelines.

Gaillard, J-C & Mercer, J 2013, 'From knowledge to action: Bridging gaps in disaster risk reduction', *Progress in human geography,* vol. 37, no. 1, pp. 93-114.

Hamilton, J & Hinton, C 2017, *Review of the Bay of Plenty Civil Defence Emergency Management Group Response to Ex-tropical Cyclones Debbie and Cook April 2017*, viewed 18/09/2018, http://www.bopcivildefence.govt.nz/media/1228/kestrel-review-of-bay-of-plenty-cdem-group-cyclone-response-final-report-20171208.pdf.

Hickford, AJ, Blainey, SP, Hortelano, AO & Pant, R 2018, 'Resilience engineering: theory and practice in interdependent infrastructure systems', *Environment Systems and Decisions*, pp. 1-14.

Kishita, Y, Hara, K, Uwasu, M & Umeda, Y 2016, 'Research needs and challenges faced in supporting scenario design in sustainability science: a literature review', *Sustainability Science,* vol. 11, no. 2, pp. 331-347.

Kok, K, Biggs, RO & Zurek, M 2007, 'Methods for developing multiscale participatory scenarios: insights from southern Africa and Europe', *Ecology and Society,* vol. 12, no. 1, p. 16.

Liu, LY, Nair, N & Wotherspoon, L 2017, *Defining and quantifying the resilience of electric power systems to natural hazards*, QuakeCoRE Annual Meeting. 3-6 September, Taupo, New Zealand.

Mauser, W, Klepper, G, Rice, M, Schmalzbauer, BS, Hackmann, H, Leemans, R & Moore, H 2013, 'Transdisciplinary global change research: The co-creation of knowledge for sustainability', *Current Opinion in Environmental Sustainability,* vol. 5, no. 3-4, pp. 420-431.

McCahon, I, Elms, D & Dewhirst, R 2017, 'Improving Resilience to Natural Disasters. West Coast Lifelines Vulnerability and Interdependency Assessment: Main Report', p. 62.

MCDEM 2002, *Civil Defence Emergency Management Act 2002*, New Zealand Government Ministry of Civil Defence & Emergency Management, Wellington.

McGinty, P 2001, 'Catalogue for a probabilistic seismic hazard analysis', *Bulletin of the New Zealand Society for Earthquake Engineering,* vol. 34, pp. 60-67.

McLean, I, Oughton, D, Ellis, S, Wakelin, B & Rubin, CB 2012, *Review of the civil defence emergency management response to the 22 February Christchurch earthquake*, New Zealand Ministry of Civil Defence & Emergency Management Wellington.

Mittelstrass, J 2011, 'On transdisciplinarity', *Trames,* vol. 15, no. 4, pp. 329-338.

Motha, J, Bradley, B, Polak, V, Thompson, E, Wald, D, Maurer, B & Van Ballegooy, S 2017, *Coupling ground motion simulation with regional modelling for rapid impact assessment*, QuakeCoRE Annual Meeting. 3-6 September, Taupo, New Zealand.

National Infrastructure Unit 2015, *The Thirty Year New Zealand Infrastructure Plan 2015*, New Zealand Government, Wellington, New Zealand.

ORC 2014, *Otago Lifelines Project: A Vulnerability and Interdependency Assessment of Otago's Lifelines Infrastructure*, Otago Regional Council (ORC). Dunedin, New Zealand.

Orchiston, C 2013, 'Tourism business preparedness, resilience and disaster planning in a region of high seismic risk: The case of the Southern Alps, New Zealand', *Current Issues in Tourism,* vol. 16, no. 5, pp. 477-494.

Orchiston, C, Davies, T, Langridge, R, Wilson, TM, Mitchell, J & Hughes, M 2016, *Alpine Fault Magnitude 8 Hazard Scenario*, viewed 8/5/2017, http://projectaf8.co.nz/wordpress/wp-content/uploads/2016/11/project-af8-hazard-model-report-final-october-2016.pdf.

Orchiston, C, Mitchell, J, Wilson, T, Langridge, R, Davies, T, Bradley, B, Johnston, D, Davies, A, Becker, J & McKay, A 2018, 'Project AF8: developing a coordinated, multi-agency response plan for a future great Alpine Fault earthquake', *New Zealand Journal of Geology and Geophysics*, pp. 1-14.

Ouyang, M 2014, 'Review on modeling and simulation of interdependent critical infrastructure systems', *Reliability Engineering & System Safety,* vol. 121, pp. 43-60.

Reed, MS, Kenter, J, Bonn, A, Broad, K, Burt, T, Fazey, I, Fraser, E, Hubacek, K, Nainggolan, D & Quinn, C 2013, 'Participatory scenario development for environmental management: A methodological framework illustrated with experience from the UK uplands', *Journal of Environmental Management,* vol. 128, pp. 345-362.

Robinson, T, Davies, T, Wilson, T & Orchiston, C 2016, 'Coseismic landsliding estimates for an Alpine Fault earthquake and the consequences for erosion of the Southern Alps, New Zealand', *Geomorphology,* vol. 263, pp. 71-86.

Robinson, T, Wilson, TM, Davies, TR, Orchiston, C & Thompson, J 2014, *Design and development of realistic exercise scenarios: a case study of the 2013 Civil Defence exercise Te Ripahapa*, GNS Science, Wellington, New Zealand.

Robinson, TR, Buxton, R, Wilson, TM, Cousins, WJ & Christophersen, AM 2015, 'Multiple infrastructure failures and restoration estimates from an Alpine Fault earthquake: Capturing modelling information for MERIT', *ERI Research Report,* vol. 2015, no. 4, p. 89.

Saidi, S, Kattan, L, Jayasinghe, P, Hettiaratchi, P & Taron, J 2017, 'Integrated infrastructure systems—A review', *Sustainable cities and society,* vol. 36, pp. 1-11.

Spangle Associates & Robert Olson Associates 1997, 'The Recovery and Reconstruction Plan of the City of Los Angeles: Evaluation of its Use After the Northridge Earthquake'. Spangle Associates Portola Valley, CA, USA.

Star, SL & Griesemer, JR 1989, 'Institutional ecology,translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39', *Social studies of science,* vol. 19, no. 3, pp. 387-420.

Stirling, M, McVerry, G, Gerstenberger, M, Litchfield, N, Van Dissen, R, Berryman, K, Barnes, P, Wallace, L, Villamor, P & Langridge, R 2012, 'National seismic hazard model for New Zealand: 2010 update', *Bulletin of the Seismological Society of America,* vol. 102, no. 4, pp. 1514-1542.

Sutherland, R, Berryman, K & Norris, R 2006, 'Quaternary slip rate and geomorphology of the Alpine fault: Implications for kinematics and seismic hazard in southwest New Zealand', *Geological Society of America Bulletin,* vol. 118, no. 3-4, pp. 464-474.

Swart, RJ, Raskin, P & Robinson, J 2004, 'The problem of the future: sustainability science and scenario analysis', *Global environmental change,* vol. 14, no. 2, pp. 137-146.

Thompson, MA, Owen, S, Lindsay, J & Leonard, G 2015, *Co-creating solutions: Engaging New Zealand in RNC research. A review of stakeholder engagement and a study of perspectives on co-creating research in NZ.*, National Science Challenges: Resilience to Nature's Challenges, Short-Term Project, New Zealand.

Walz, A, Lardelli, C, Behrendt, H, Grêt-Regamey, A, Lundström, C, Kytzia, S & Bebi, P 2007, 'Participatory scenario analysis for integrated regional modelling', *Landscape and Urban Planning,* vol. 81, no. 1, pp. 114-131.

West Coast Regional Council 2014, 'West Coast Regional Weather Event: Ex Tropical Cyclone Ita, 17 April 2014', p. 30.

Zorn, C, Pant, R, Thacker, S, Shamseldin, A & Andreae, L in review-a, 'Quantifying vulnerabilities across connected electricity and transportation infrastructure networks in New Zealand', *Manuscript submitted for publication.*

Zorn, C, Thacker, S, Pant, R & Shamseldin, A in review-b, 'Evaluating the magnitude and spatial extent of disruptions across interdependent national infrastructure networks', *Manuscript submitted for publication.*

6. Conclusions

This chapter presents a summary of the thesis conclusions. It builds on the research, discussions and conclusions presented in the previous chapters. An opening summary is followed by an outline of real-world benefits resulting from this doctoral project, and discussions of research limitations and fundamental contributions. The chapter concludes with recommendations for future research and recommendations for policymakers and practitioners.

6.1 Thesis summary

While hazards and impacts may be regional, disasters are local events, which first and foremost affect local communities (Gaillard & Mercer, 2013). This understanding has contributed to growing recognition of the need to involve community members in disaster resilience decision-making that is likely to affect them (Ackerman, 2004; Gaillard & Mercer, 2013; Maskrey, 2011; Murphy et al., 2014; Pearce, 2003). The need for inclusive, participatory, approaches to disaster impact reduction has also become a political and policy priority. For example, the United Nations 2015-2030 Sendai Framework for Disaster Risk Reduction includes the following 'guiding principle': 'Disaster risk reduction requires an all-of-society engagement and partnership. It also requires empowerment and inclusive, accessible and non discriminatory participation, paying special attention to people disproportionately affected by disasters, especially the poorest. A gender, age, disability and cultural perspective should be integrated in all policies and practices, and women and youth leadership should be promoted. In this context, special attention should be paid to the improvement of organized voluntary work of citizens' (UNISDR, 2015, 19d, p. 13).

Participatory approaches are needed to increase community involvement in efforts to reduce the impacts of disasters, including disruption of essential services. However, to date, the divide in resilience definitions identified by White and O'Hare (2014) has resulted in largely parallel bodies of literature and practice, focussed either on the relationship between infrastructure and resilience, or on the use of participatory governance to build resilience at the community level. Hence, there has been very little research combining these findings into more holistic approaches to build community resilience.

This doctoral project aimed to address this gap in the field by developing and trialling an inclusive participatory approach to increase the resilience of a remote community to loss of essential services due to disaster damage to infrastructure, as an integrated component of wider initiatives to reduce inequities and effect social transformation.

This aim was achieved by:

1. **Identifying factors that affect the resilience of remote communities at risk of isolation from disasters triggered by natural hazards.**
   Systematic review methodology was used to bring together for the first time articles concerned with the resilience of remote communities at risk of isolation following disasters

triggered by natural hazards (Chapter 2). The review showed that, besides the well-established reasons for inclusive participatory disaster resilience decision-making outlined above, for a disaster impact reduction initiative to succeed in a remote community, community members must adopt and take ownership of the initiative (Remling & Veitayaki, 2016; Chapter 2). This was shown to be because community members in remote settlements are often relied upon to implement resilience measures, both due to a shift of responsibility onto community members as essential services are increasingly centralised for cost efficiency (Remling & Veitayaki, 2016) and because, if the settlement is isolated, community members will need to lead immediate response efforts in the absence of authorities, sometimes for considerable periods of time (Gardner, 2015; Orchiston, 2013). Therefore, if community members are not involved in disaster resilience decision-making, or do not trust the outcomes, they are not likely to implement the proposed disaster impact reduction measures (Eiser et al., 2012).

Further, while there are efforts to increase the resilience of remote communities which are dependent on distributed infrastructure by increasing the resilience of that infrastructure, there remains very little research that combines these efforts with community-inclusive participatory disaster resilience decision-making (White & O'Hare, 2014). This omission is consistent with the normative disciplinary tendency, identified by White and O'Hare (2014), to use the term “resilience” to refer either to preserving, maintaining and restoring the built environment (including infrastructure), or to addressing the social inequities which increase the vulnerability of communities. To date, this has resulted in parallel bodies of literature (and practice) focussed either on the relationship between distributed infrastructure and community resilience, or on the use of participatory governance to build resilience at the local level. Increasing the resilience of remote communities effectively requires a participatory approach that integrates socio-cultural transformation and the reduction of disruption to essential services (Chapter 2).

The need for both improvements in the provision of essential services and for socio-cultural transformation to build the resilience of remote communities was demonstrated by an impact assessment of the 2016 M_w 7.8 “Kaikōura” earthquake (Chapter 3). This assessment focussed on impacts to distributed transport infrastructure, which was particularly disrupted in the event. Strong resilient characteristics of the New Zealand infrastructure system were evident, including the value of resilient design and the country’s service- rather than asset-based approach (Chapter 3). However, the event also highlighted the vulnerability of New Zealand’s distributed infrastructure networks, which have little or no redundancy throughout the country; demonstrated the dependence of remote New Zealand communities on distributed infrastructure for service delivery; and highlighted the need for remote communities in New Zealand to be better prepared for potential isolation from known future hazards, such as an Alpine Fault earthquake (Chapter 3). One of the major challenges following the earthquake was prioritisation of road access between repair of the road, (emergency) supplies for and evacuation from Kaikōura, and access for residents (including farmers) (Chapter 3). Pre-disaster participatory decision-making could have addressed this challenge, educating each stakeholder group about the needs of the other groups. Challenges and decision-making prioritisation could have been discussed, allowing every stakeholder group to input into this decision-making process, and for all groups to have a clearer understanding of the reasoning behind decisions. This likely would have eased tensions during the response as each stakeholder group would have had more realistic expectations and would have been empowered to be better prepared for the emergency response.

2. **Developing a participatory approach to integrate disaster impact reduction planning across stakeholder domains, to increase the resilience of remote communities at risk of isolation from disasters triggered by natural hazards.**

   This thesis established an inclusive participatory disaster resilience decision-making approach by integrating a successful approach to increasing distributed infrastructure resilience - using a hazard event scenario as a boundary object to enable collaboration between decision-makers - with community-inclusive participatory disaster resilience decision-making (Chapter 4). By sequencing and combining various (existing) participation methodologies, stakeholders can engage with and gain more influence over the process at relevant scales (i.e. local, regional, or national), and the process can be designed to suit the participation capacities of each stakeholder group. This allows community members, practitioners and researchers to draw from the same knowledge base when making decisions, and achieve consensus where collaborative decision-making is appropriate. This approach is highly-applicable for remote communities, addressing the urgent need of increasing the resilience of a remote community to loss of essential services due to disaster damage to infrastructure, as an integrated component of wider initiatives to reduce inequities and effect social transformation.

3. **Partnering with a remote community to apply the participatory approach, and demonstrating its capacity to integrate autonomous initiatives driven by any of the participating stakeholder groups into the approach.**

   The participatory approach was applied in a “pre-disaster” collaboration between Franz Josef community members, infrastructure and emergency management stakeholders, and university researchers (Chapter 4). An Alpine Fault earthquake scenario (the AF8+ scenario) was used as the boundary object. This application established that the approach enabled feedback loops, allowing stakeholder groups to iteratively build on the impacts scenario, and to co-produce knowledge across knowledge domains. Moreover, because stakeholders could understand other stakeholders’ contributions, they were able to utilise these contributions immediately to assess existing, and implement new, resilience measures in the real world.

It was subsequently established that autonomous initiatives could also be incorporated into the approach using an infrastructure modelling framework (Chapter 5). Utilisation of the established feedback loops increased the shared ownership of the modelling, and improved other stakeholders' disaster resilience assessments. This integration also validated the modelling, which could then be further improved by the stakeholder input and critique. In addition, the modelling was able to demonstrate the national implications of this community's local impact assessment, allowing the community assessment to be communicated more clearly to national government, and increasing the likelihood of relevant national-level disaster impact reduction policies for the community.

6.2 Achieved real-world benefits

It is also important to acknowledge that in addition to addressing the core thesis aims, the application of this participatory approach (outlined above) also produced actionable "real world" benefits. Appendix G details workshop outcomes in full, but examples include:

- Franz Josef community members taking control of their own preparation, identifying that following disasters they could self-ration to ensure that supplies will last (Chapter 4);
- Road operators identifying that it would be beneficial to empower locally-based roading contractors to automatically help repair local infrastructure, including roads, water pipes, and sewerage, in the event of a disaster of similar magnitude to the AF8+ scenario, rather than attempting to open State Highways which would require a structured, centrally-led and -resourced response (Chapter 4);
- Validation of ongoing work to introduce embedded electricity generation and back up supplies on the West Coast (Chapter 5);
- Workshop maps being useful and used for business crisis management, as noted by Franz Josef business owners (Chapter 4);
- Workshops highlighting gaps in shared understanding which were then able to be addressed during or after the workshops, including discussions of who has the right to open and close local roads (Chapter 4).

6.3 Limitations

This doctoral thesis successfully developed and applied a participatory governance approach to increase the resilience of remote communities to natural hazards (Section 6.1), and so achieved its major objective. It is useful to note, however, that despite this achievement, the AF8+ scenario-based participatory approach was not without limitations. Below, key areas for improvement are identified and discussed:

- **More integration between scenarios:** To create the hazard scenario, the existing Project AF8 scenario was up-scaled (Chapter 4). Scaling reduced the time and resources required to develop the scenario, and also provided additional benefits, such as increased interest in participation, but was difficult because Project AF8 produced a fragmented scenario (Chapter 4). Greater integration between the original Project AF8 application and the participatory process developed in this thesis could have enhanced both, and is worth considering for future large-scale scenario-based disaster resilience projects.

- **More participation methodologies:** While combining and sequencing methodologies enabled the successful integration of stakeholders in this process, the exclusive use of workshops limited the approach (Chapter 5). Complete participation is a near impossibility for any project of this scale (Reed et al., 2013) but combining a wider range of participation methodologies, for example, by holding open meetings or using surveys in addition to the workshops, could have reduced this limitation and increased participation in the process.
- **More open participation processes:** Only the "relevant" stakeholders were invited to workshops. This had the advantage of ensuring that each stakeholder group was able to discuss their views openly, and if necessary, confidentially. While mostly driven by increased convenience, the "closed" nature of many of the workshops was in part driven by stakeholder groups' concerns about negative publicity, given that discussing disasters and response strategies can be a sensitive topic, especially in a tourist town. However, Aoki (2018) provides evidence that allowing all stakeholders to participate in all parts of a process (enabled by varying influence weightings, such as only participating as observers) can increase trust in decision-making and speed up the overarching process, as fewer questions need to be asked about how and why decisions are or were made. It is worth noting that this requires greater "buy-in" from participating stakeholder groups, along with sustained interest. However, promisingly, as also found in Franz Josef, the often "tight-knit" character of remote communities can help to enable participatory governance (Chapter 2). Therefore, while the process, and particularly the "combined" workshop, disseminated outcomes from previous workshops, the process would probably have benefitted from allowing all stakeholders to participate in all parts of the process. This could have been enabled through livestreaming of workshops to social media, as well as by inviting participants to observe and ask questions in all workshops (Aoki, 2018) (Chapter 4).
- **More logical sequencing:** The sequence of the workshops could also have been improved. While the lifelines workshop and "combined" workshop allowed direct discussions of interdependencies, holding the workshops in order of reducing scale (i.e. national, then regional, then local) would have reduced assumptions required within the initial workshops.
- **Greater mandate:** The approach suffered when national telecommunications and electricity providers/distributors did not engage with the process. The vulnerability of the approach due to its voluntary nature was also highlighted when key stakeholders could not attend due to other priorities. The lack of engagement from some stakeholder groups decreased the scenario credibility and increased the influence of other stakeholders (particularly researchers) on the scenario, as their judgement was used as a substitute for those who did not participate. High staff turnover (alongside community members) and sustaining interest also presented challenges. While part of the project's success was due to the close

collaboration between researchers and the West Coast Engineering Lifelines Group, closer collaboration could have encouraged more participation. For example, making the project a formal West Coast Engineering Lifelines Group project may have encouraged participation from telecommunications providers. Legislation is also an option which has been successful in New Zealand at effectively mandating collaboration between infrastructure companies and emergency managers (MCDEM, 2002). Clarifying and, if necessary, strengthening this mandate could greatly increase necessary collaboration between community members and lifelines organisations.

- **More stakeholder evaluation:** There was little structured stakeholder evaluation of the scenario-based participatory approach. In each AF8+ workshop, feedback was encouraged at all times through a "feedback station" and at the end of each workshop there was also a brief discussion where participants were again invited to provide feedback. Such feedback is clearly limited in its scope to evaluate the approach and its outcomes. What constitutes successful scenario planning is different for different people, and so is challenging, contentious, and worthy of (more detailed) evaluation by all participants (Reed et al., 2008; Wodak & Neale, 2015). However, the research team kept in very close contact with participants from all of the stakeholder groups throughout. This provided important feedback which could be, and was, used dynamically throughout the process (Chapter 4).
- **More sustained collaboration:** Finally, the AF8+ scenario planning process stopped short of efforts to sustain collaboration, which can be critical to the success of disaster impact reduction (Blake et al., 2011; Fenwick, 2012; Robinson et al., 2014). Sustained collaboration between infrastructure companies and emergency managers has been successful in New Zealand due to its strong lifelines culture (Chapter 3). Involving community members in lifelines groups' work may be a way to ensure ongoing collaboration with community members for disaster impact reduction. The existing collaboration is effectively legislated between infrastructure companies and emergency managers in New Zealand (MCDEM, 2002), and enabled by lifeline groups. Again, strengthening this mandate could greatly increase necessary collaboration between community members and lifelines groups.

6.4 Implementation

This research project benefitted from two key influences which aided implementation. First, the application of this approach particularly benefitted from New Zealand's strong "lifelines" culture. Lifeline utilities are legislated to improve disaster readiness, reduction, response, and recovery in New Zealand (MCDEM, 2002), but the additional leadership and willingness to participate in this process shown by the West Coast Engineering Lifelines Group, and in particular NZ Transport Agency and Westpower, alongside regional Civil Defence & Emergency Management (CDEM) Groups, was essential to the success of this voluntary process. Second, both the *National Science Challenge Resilience to Nature's Challenges* and *Project AF8* are major national research programmes (Chapter 4), which gave this research project and the Franz Josef community national prominence and made the community a focal point for resilience planning in the West Coast region. Accordingly, pre-existing relationships between researchers and community members, and the applied focus of research funding in New Zealand, created a unique situation where researchers were able to support the request of community members who wished to increase the resilience of their community. Backed by substantial resources, including financial resource which councils typically cannot afford to spend, researchers enabled an empowering opportunity for community members to collaborate and discuss community resilience. Community members used this space to workshop ideas before presenting these to councils (in a working group indirectly triggered by the community/researcher collaboration; Section 4.2.1.1). This work has particular application for readiness and reduction measures, as well as pre-disaster recovery planning which can be rapidly fed into response and recovery processes. Accordingly, the research funding created a heighted, unusual situation, where the researcher involvement likely had a positive influence on resilience planning for the community, both in terms of available resources and influence on both policymakers and practitioners to participate.

However, despite these influences, the approach still suffered when infrastructure stakeholders either did not or could not engage with the process (Chapter 4). Further, while the research project stopped short of efforts to maintain collaboration (Section 6.3), the collaborative process has also not been picked up by policymakers or practitioners. As researchers led the process but stopped short of efforts to establish sustain collaboration, without leadership from a stakeholder group, the benefits of the application may be short-lived. Equally, the developed approach, which could be used with other communities, has not been, despite explicit requests from community members from Fox Glacier, Ōkārito and Whataroa.

The developed approach also has applicability beyond remote communities alone. For example, applying the approach to other sudden-onset hazards, such as avalanches, debris flows, flash floods, tsunami and volcanic lahars, may be particularly rewarding. Communities dealing with sudden-onset hazards are, similarly to remote communities, likely to be alone when responding to warnings and the first to respond to a disaster. Further, the research has applicability to managed retreat discussions in general, including those focussed around climate change. Again, for managed retreat to succeed, community members must adopt and take ownership of the initiative (Few et al., 2007), which this approach enables.

Therefore, while there was evident need for this research project, approaches addressing both the provision of essential services and socio-cultural transformation are of such importance that they should be mandated as policy and undertaken without requiring the involvement of researchers. In New Zealand, legislation has been successful at effectively mandating collaboration between infrastructure companies and emergency managers (MCDEM, 2002). Clarifying, and if necessary, strengthening this mandate would provide accountability to greatly increase necessary collaboration between community members, policymakers and practitioners. CDEM Groups are well-positioned to lead such collaborative work, but face resource constraints. Participatory processes require substantial time, trained staff, and financial resources which can limit implementation. Therefore, the low resources currently afforded to CDEM Groups suggest that the current system may not be optimal for the resilience of remote communities in New Zealand.

6.5 A fundamental contribution: bridging the knowledge divide

This thesis has addressed the fundamental divide between “equilibrist” and “evolutionary” definitions of resilience, identified by White and O'Hare (2014), where “evolutionary resilience” emphasises social change and adaptation while “equilibrist resilience” emphasises preservation and restoration of the built environment (White & O'Hare, 2014). These differing definitions lay the foundation for differing policy outcomes, but White and O'Hare (2014) find an overwhelming tendency towards “equilibrist” definitions of “resilience” in policy, largely neutralising the transformative potential of “evolutionary” definitions.

This thesis has also demonstrated that bridging this divide is of critical importance for remote communities, which rely as heavily on socio-cultural transformation (“evolutionary resilience”) as they do on the provision of essential services (“equilibrist resilience”). Driven both by new development opportunities which rely on distributed infrastructure and by the increasing centralisation of essential services (Gardner, 2015; Chapter 2), many remote communities have increasing vulnerability and decreasing disaster resilience due to their dependence on distributed infrastructure, substantially increasing the negative consequences of isolation (Murphy et al., 2014). Therefore, resilient distributed infrastructure is an essential component of the resilience of remote communities. Further, besides the well-established reasons for inclusive participatory disaster resilience decision-making (see Reed, 2008, for a summary), for a disaster impact reduction initiative to succeed in a remote community, community members must adopt and take ownership of the initiative (Remling & Veitayaki, 2016; Chapter 2). This is because community members in remote settlements are often relied upon to implement resilience measures, both due to a shift of responsibility onto community members as essential services are increasingly centralised for cost efficiency (Remling & Veitayaki, 2016) and because, if the settlement is isolated, community members will need to lead immediate response efforts in the absence of authorities, sometimes for considerable periods of time (Gardner, 2015; Orchiston, 2013). Therefore, if community members are not involved in disaster resilience decision-making, or do not trust the outcomes, they are not likely to implement the proposed disaster impact reduction measures (Eiser et al., 2012).

The need for this whole-of-society (combined “equilibrist” and “evolutionary”) approach for disaster resilience is a well-established political and policy priority, featuring, for example, in the multinational 2015-2030 Sendai Framework for Disaster Risk Reduction. Further, both infrastructure companies and community members are explicitly asking for collaborative processes between community members, practitioners and policymakers (Chapter 4). However, even within the Sendai Framework’s ‘all of society’ guiding principle (UNISDR, 2015, 19d, p. 13), societal and infrastructure resilience are addressed in entirely separate sections (UNISDR, 2015). Approaches aiming to increase resilience are also separate as a result of the divergent definitions of resilience (White & O'Hare, 2014). This disciplinary gap makes combining these approaches an enormously difficult task (White & O'Hare, 2014), beyond the well-documented difficulties of increasing resilience in either the “equilibrist” or “evolutionary” interpretations of the term also demonstrated throughout this thesis.

Therefore, this thesis has provided a fundamental contribution to disaster resilience efforts by demonstrating that it is possible to bridge “equilibrist” and “evolutionary” disciplinary approaches. By developing and applying an “evolutionary” participatory governance approach to bring together community members, practitioners, policymakers and researchers, the participating stakeholder groups were all able to better understand the likely disruption, resulting from disaster damage to distributed infrastructure networks, and to make decisions to reduce both that disruption and the social consequences of it. In doing so, this increased the resilience of a remote community to natural hazards.

6.6 Recommendations for future research

This project has identified several recommendations for future research. Overall, rising disaster losses and the ongoing centralisation of essential services make the need for more research concerned with the resilience of remote communities at risk of isolation following disasters urgent and timely (Chapter 2). Continued development and establishment of participatory governance is essential to increase the resilience of remote communities. More specific recommendations are outlined below:

6.6.1 Participatory governance research recommendations

- **Matauranga Māori:** The prevalence of studies focussed on community-led planning in remote indigenous communities in Australia and Canada reflects the marginalisation of these communities as a result of recent colonisation and a need for further research focussed on indigenous communities. This prevalence also highlights the surprising absence of publications focussed on the disaster resilience of remote Māori communities, despite New Zealand’s recent history of colonisation and official status as a bicultural nation. There is an urgent need for research in this area.
- **Transferability:** The scenario-based participatory approach is highly transferable. However, this has not been tested. It would be relatively easy to now use the existing AF8+ hazard scenario with numerous other South Island communities. This highlights an advantage of the method used to create the scenario in the applied methodology. Further, the scenario-based participatory approach could be applied with multiple communities at once, in a different location, and with entirely different scenarios.
- **Multi-hazard applicability:** Outside of rural communities alone, applying the approach to other sudden-onset hazards, such as avalanches, debris flows, flash floods, tsunami and volcanic lahars, may be particularly rewarding. Communities dealing with sudden-onset hazards are, similarly to remote communities, likely to be alone when responding to warnings and the first

to respond to a disaster. Further, the research has applicability to managed retreat discussions in general, including those focussed on climate change.

- **Integrating stakeholder groups' initiatives:** While the integration of independent initiatives into the participatory approach has been proven possible by the integration of an end-to-end modelling framework (Chapter 5), this has not been demonstrated for more than one application. The integration of the independent initiative both advanced the modelling and the participatory assessments in a feedback loop. Further, this integration highlighted areas for improvement or greater consideration in both. Accordingly, integrating independent stakeholder groups' initiatives would be worth pursuing as these could be of considerable value in both improving the stakeholder group's initiative, as well as advancing the shared understanding co-created by all of the participating stakeholder groups.
- **Scenario magnitude:** The literature lacks guidance on how stakeholders should develop hazard scenarios for scenario-based participatory approaches. This includes how to establish the appropriate severity of any scenario (e.g. whether a scenario may be "too scary" or "not scary enough"). There is debate but little to no guidance in the literature as to whether an entirely catastrophic event may be too alarming or too large for a community to comprehend. Further, while "worst-case scenarios" are often used, Robinson et al. (2018) find planning for worst-case scenarios may be an unnecessarily large burden on limited resources available for disaster impact reduction. This is an area in which greater documentation and further research would be valuable (Chapter 4).
- **Participant identification:** Systematic identification and selection of participants is required to ensure participatory processes are as little biased as possible. For a full review of methods to identify who should be involved in scenario-based participatory approaches, see Reed et al. (2009). While the literature offers good guidance on this issue, this is a step that is rarely taken and must be considered more in the future (Reed et al., 2013; Chapter 4).
- **Uptake:** As discussed above, the participatory approach suffered when national telecommunications and electricity providers/distributors did not engage with the process. However, as also discussed, the development of trusting relationships takes time (Eiser et al., 2012). This participatory approach has been among the first to develop collaborative, cross-disciplinary and cross-university stakeholder relationships as part of a long-term collaboration programme under the New Zealand *National Science Challenges'* research project *Resilience to Nature's Challenges.* It thus offers the opportunity to build strong and lasting relationships within the research community, and to leverage existing relationships, such as those developed in this project. Continuing to build on and develop this approach offers the potential to greatly improve engagement in projects, offering benefits for both researchers and stakeholders.
- **Training:** With a clear need for more participatory approaches, there is also a need for more skilled facilitators. Therefore, more investment in training is required. To better enable this, more research into how to train skilled facilitators is also required, given that how to train facilitators is currently unclear (Chapter 4).

- **Evaluation:** There are a lack of evaluation criteria and data collection methods for transdisciplinary research, including the scenario-based approach developed herein (Holzer et al., 2018; Reed, 2008). The development and use of evaluation methodologies for transdisciplinary research outcomes remain important matters for future studies to address.
- **Publication opportunities:** More broadly, there are a lack of reputable journals to publish discipline-spanning research, stunting the growth of much-needed research in research areas such as that discussed in this thesis.

6.6.2 Integrated modelling research recommendations

Several extensions to the integrated modelling discussed in Chapter 5 are required both to i) assess the generalised recovery strategies and priorities across a wider range of potential hazard event scenarios, particularly building on the need to focus on recovery and not just on the initial response; and ii) to improve the application of the integrated framework in future projects:

- The formal interlinking of hazard models, such as ground motion (Bradley et al., 2017), landslides (Robinson et al., 2016) and liquefaction (Motha et al., 2017), can provide a range of realistic inputs and allow model updates to be easily included when available. Improvements are further envisaged across each of the infrastructure sector models.
- In addition to improving asset data quality and quantity and formalising attributes (such as whether assets are buried/overhead and if redundant electricity supplies are present), process-based sector models (i.e. power flow, water supply hydraulics, traffic flow) would be desirable for more accurately modelling user disruptions.
- Building detailed calibrated network models at a South Island scale is difficult given the extensive data requirements and inherent computation costs, depending on the desired resolutions. Several of these wider infrastructure network process models are in development through the research initiatives including QuakeCoRE and the Resilience to Nature's Challenges National Science Challenge (e.g. Liu et al., 2017). The research in this thesis confirms that these models will offer considerable value.
- Similarly, there is further opportunity to provide a more robust assessment of damage and recovery at local/neighbourhood scales by incorporating the highly detailed water supply network fragility and recovery models of Bellagamba et al. (2018), without the need for extensive hydraulic modelling.
- Further, population movements (and therefore demands), transportation network behaviours (i.e. origin-destination pairings) and changing dependencies will adjust our definitions of "normal" service levels. Taking these into account will allow a more accurate representation of the true user disruption as opposed to pre-event comparisons, which are better suited to lower-intensity events.
- The temporal resolution of any model updates should also be carefully considered to allow integration of modelling and stakeholder inputs and verification.

- Finally, while it is possible to integrate hazard and infrastructure modelling today, doing so is challenging. Demonstrating the value of end-to-end modelling will hopefully encourage future modelling to be designed to be compatible with integrated modelling frameworks.

6.7 Recommendations for policymakers and practitioners

Finally, this project has identified several recommendations for policymakers and practitioners:

- Ellemor (2005) and Aoki (2018) both discuss the advantages of employing members of relevant remote communities in relevant organisations and government agencies. This would likely further increase the mutual trust and understanding required for effective participation, while also building capacity to contribute by supplementing income and dedicating the time of community members to improving the community resilience, as well as raising awareness inside government agencies of the needs and value offered by particularly vulnerable communities (Ellemor, 2005) (Chapter 2).
- The 2016 M_w 7.8 “Kaikōura” earthquake highlighted the vulnerability of New Zealand’s regional transportation networks, which have limited or no redundancy in some cases (Chapter 3). It is critical to address this issue in the area affected, and in other vulnerable regions. High-functioning alternative route redundancy, which can perform if another route or line is damaged (an area NZ Transport Agency had already identified as requiring improvement), is evidently needed (New Zealand Transport Agency, 2014; Wilson et al., 2016). This includes both the need for new routes to add redundancy and the need to upgrade existing routes to enable them to function as effective diversions for extended periods. Using the diversion for State Highway 1 as an example, while the longer route and increased volumes of traffic inevitably increased travel times, travel times along the alternative route could have been improved by pre-event measures including strengthening the pavement to cope with heavier truck loads, placing sufficient passing bays for high volumes of traffic, and building two-way traffic bridges at locations that could become bottlenecks under high traffic flows, instead of implementing these measures post-earthquake.
- While all settlements had road access by Day 23 following the “Kaikōura” earthquake, CDEM currently advises residents to be prepared with 7 days of emergency supplies. Although helicopter and (to some extent) sea access were sufficient during this event, the event also highlighted the unreliability of these modes of emergency transport. This evidence, along with scenarios being produced for other potential hazardous events, such as an Alpine Fault rupture scenario that suggests air response may be limited (Robinson et al., 2015), mean that the length of time without road access seen in Kaikōura could be a realistic example of the length of time people should be prepared to be isolated for. This highlights the importance of realistic preparedness, and the need to address the gap between recommendations and expected future events.

- To improve readiness and reduction measures, as well as pre-disaster recovery planning which can be rapidly fed into response and recovery processes, there is a need to empower communities; develop relationships between community members, practitioners and policymakers; make space for communities to make requests to councils; and work with communities to act on requests. Pre-existing relationships between researchers and community members, and the applied focus of research funding in New Zealand, created a unique situation where researchers were able to support the request of community members who wished to increase the resilience of their community. Backed by substantial resources, including financial resource which councils typically cannot afford to spend, researchers enabled an empowering opportunity for community members to workshop ideas before presenting these to councils. Accordingly, the research funding created a heighted, unusual situation, where researcher involvement likely had a positive influence on resilience planning for the community, both in terms of available resources and influence on both policymakers and practitioners to participate. Work must be undertaken to make such situations the norm.
- With a clear need for more participatory approaches, there is also a need for more practitioners and policymakers to be trained or employed as skilled facilitators. Facilitators are essential for government organisations and infrastructure companies to increase collaboration with community members, which is critical to increase the resilience of remote communities.
- New Zealand's resilient "lifelines" culture continues to repeatedly demonstrate its abundant value to New Zealand. This was demonstrated both during the "Kaikōura" earthquake (Chapter 2) and through the application of this participatory approach, which particularly benefitted from the additional leadership and willingness to participate in this process shown by the West Coast Engineering Lifelines Group, and in particular NZ Transport Agency and Westpower, alongside regional Civil Defence & Emergency Management (CDEM) Groups. Continued investment to support this collaboration, such as through supporting forums and research projects, is of notable value, and may offer the best way forward to greatly increase necessary collaboration between community members and lifelines groups.
- Finally, approaches addressing both the provision of essential services ("equilibrist resilience") and socio-cultural transformation ("evolutionary resilience") are of such importance that they should be mandated as policy and undertaken without requiring the involvement of researchers. In New Zealand, legislation has been successful at effectively mandating collaboration between infrastructure companies and emergency managers (MCDEM, 2002). Clarifying, and if necessary, strengthening this mandate would provide accountability to greatly increase necessary collaboration between community members, policymakers and practitioners. CDEM Groups are well-positioned to lead such collaborative work, but face resource constraints. Participatory processes require substantial time, trained staff, and financial resources which can limit implementation. Therefore, the low resources currently afforded to CDEM Groups suggest that the current system may not be optimal for the resilience of remote communities in New Zealand.

6.8 References

Ackerman, J 2004, 'Co-governance for accountability: beyond “exit” and “voice”', *World Development,* vol. 32, no. 3, pp. 447-463.

Aoki, N 2018, 'Sequencing and combining participation in urban planning: The case of tsunami-ravaged Onagawa Town, Japan', *Cities,* vol. 72, pp. 226-236.

Bellagamba, X, Bradley, B, Wotherspoon, L & Hughes, M 2018, *Development of fragility functions for buried pipelines based on New Zealand data*, Proceedings of the 16th European Conference on Earthquake Engineering, 18-21 June, Thessaloniki, Greece.

Blake, ES, Landsea, CW, Gibney, EJ & Asheville, N 2011, 'The deadliest, costliest, and most intense United States tropical cyclones from 1851 to 2010 (and other frequesntly requested hurricane facts)'. NOAA Technical Memorandum NWS NHC-6, Miami, Florida, US.

Bradley, BA, Bae, SE, Polak, V, Lee, RL, Thomson, EM & Tarbali, K 2017, 'Ground motion simulations of great earthquakes on the Alpine Fault: effect of hypocentre location and comparison with empirical modelling', *New Zealand Journal of Geology and Geophysics*, pp. 1-11.

Eiser, JR, Bostrom, A, Burton, I, Johnston, DM, McClure, J, Paton, D, Van Der Pligt, J & White, MPJIJoDRR 2012, 'Risk interpretation and action: A conceptual framework for responses to natural hazards', vol. 1, pp. 5-16.

Ellemor, H 2005, 'Reconsidering emergency management and indigenous communities in Australia', *Global Environmental Change Part B: Environmental Hazards,* vol. 6, no. 1, pp. 1-7.

Fenwick, A 2012, *The Value of Lifeline Seismic Risk Mitigation in Christchurch: Summary Report, June 2012*, New Zealand Lifelines.

Few, R, Brown, K & Tompkins, ELJCp 2007, 'Public participation and climate change adaptation: avoiding the illusion of inclusion', vol. 7, no. 1, pp. 46-59.

Gaillard, J-C & Mercer, J 2013, 'From knowledge to action: Bridging gaps in disaster risk reduction', *Progress in human geography,* vol. 37, no. 1, pp. 93-114.

Gardner, JS 2015, 'Risk complexity and governance in mountain environments', in FP Urbano (ed.), *Risk governance: The Articulation of Hazard, Politics and Ecology*, Springer, Dordrecht, pp. 349-371.

Holzer, JM, Carmon, N & Orenstein, DE 2018, 'A methodology for evaluating transdisciplinary research on coupled socio-ecological systems', *Ecological Indicators,* vol. 85, pp. 808-819.

Liu, LY, Nair, N & Wotherspoon, L 2017, *Defining and quantifying the resilience of electric power systems to natural hazards*, QuakeCoRE Annual Meeting. 3-6 September, Taupo, New Zealand.

Maskrey, A 2011, 'Revisiting community-based disaster risk management', *Environmental Hazards,* vol. 10, no. 1, pp. 42-52.

MCDEM 2002, *Civil Defence Emergency Management Act 2002*, New Zealand Government Ministry of Civil Defence & Emergency Management, Wellington.

Motha, J, Bradley, B, Polak, V, Thompson, E, Wald, D, Maurer, B & Van Ballegooy, S 2017, *Coupling ground motion simulation with regional modelling for rapid impact assessment*, QuakeCoRE Annual Meeting. 3-6 September, Taupo, New Zealand.

Murphy, BL, Anderson, GS, Bowles, R & Cox, RS 2014, 'Planning for disaster resilience in rural, remote, and coastal communities: Moving from thought to action', *Journal of emergency management,* vol. 12, no. 1, p. 16.

Orchiston, C 2013, 'Tourism business preparedness, resilience and disaster planning in a region of high seismic risk: The case of the Southern Alps, New Zealand', *Current Issues in Tourism,* vol. 16, no. 5, pp. 477-494.

Pearce, L 2003, 'Disaster management and community planning, and public participation: how to achieve sustainable hazard mitigation', *Natural hazards,* vol. 28, no. 2-3, pp. 211-228.

Reed, MS 2008, 'Stakeholder participation for environmental management: a literature review', *Biological conservation,* vol. 141, no. 10, pp. 2417-2431.

Reed, MS, Dougill, AJ & Baker, TR 2008, 'Participatory indicator development: what can ecologists and local communities learn from each other', *Ecological Applications,* vol. 18, no. 5, pp. 1253-1269.

Reed, MS, Graves, A, Dandy, N, Posthumus, H, Hubacek, K, Morris, J, Prell, C, Quinn, CH & Stringer, LC 2009, 'Who's in and why? A typology of stakeholder analysis methods for natural resource management', *Journal of environmental management,* vol. 90, no. 5, pp. 1933-1949.

Reed, MS, Kenter, J, Bonn, A, Broad, K, Burt, T, Fazey, I, Fraser, E, Hubacek, K, Nainggolan, D & Quinn, C 2013, 'Participatory scenario development for environmental management: A methodological framework illustrated with experience from the UK uplands', *Journal of Environmental Management,* vol. 128, pp. 345-362.

Remling, E & Veitayaki, J 2016, 'Community-based action in Fiji’s Gau Island: a model for the Pacific?', *International Journal of Climate Change Strategies and Management,* vol. 8, no. 3, pp. 375-398.

Robinson, T, Davies, T, Wilson, T & Orchiston, C 2016, 'Coseismic landsliding estimates for an Alpine Fault earthquake and the consequences for erosion of the Southern Alps, New Zealand', *Geomorphology,* vol. 263, pp. 71-86.

Robinson, T, Wilson, TM, Davies, TR, Orchiston, C & Thompson, J 2014, *Design and development of realistic exercise scenarios: a case study of the 2013 Civil Defence exercise Te Ripahapa*, GNS Science, Wellington, New Zealand.

Robinson, TR, Rosser, NJ, Densmore, AL, Oven, KJ, Shrestha, SN & Guragain, R 2018, 'Use of scenario ensembles for deriving seismic risk', vol. 115, no. 41, pp. E9532-E9541.

UNISDR 2015, *Sendai Framework for Disaster Risk Reduction 2015-2030*, UNISDR, Sendai, Japan.

White, I & O'Hare, P 2014, 'From rhetoric to reality: which resilience, why resilience, and whose resilience in spatial planning?', *Environment and Planning C: Government and Policy,* vol. 32, no. 5, pp. 934-950.

Wodak, J & Neale, T 2015, 'A critical review of the application of environmental scenario exercises', *Futures,* vol. 73, pp. 176-186.

Appendix A. Assessment of multi-hazard exposure on regional infrastructure, in the West Coast region, New Zealand

Alistair J. Davies[1], Tim R. H. Davies[1], Thomas M. Wilson[1], Thomas R. Robinson[2], Theo Kritikos[3]

[1] University of Canterbury, Christchurch, New Zealand.

[2] University of Durham, Durham, United Kingdom.

[3] Stronger Christchurch Infrastructure Research Team, Christchurch, New Zealand.

Conference: 1st International Conference on Natural Hazards and Infrastructure

Published: June 2016

Appendix A. Assessment of multi-hazard exposure on infrastructure in the West Coast region, NZ.

1. Abstract

Many remote communities are increasingly dependent upon regional critical infrastructure and so are at risk of infrastructure impacts resulting from natural hazards. Thus, isolated communities are not only at risk from hazards which affect their location, but also from hazards that affect the distributed infrastructure they rely on, even if the community is not directly affected. Reducing infrastructure risk can therefore increase community resilience and reduce response and recovery times following a disaster. The West Coast region of the South Island, New Zealand, is a global tourist destination with numerous isolated communities and linear infrastructure corridors that are exposed to a variety of natural hazards, including earthquakes, landslides, debris flows and flooding. By combining a number of previously modelled hazard exposures and overlaying the location of the road network in the West Coast region, the locations where the road network is most exposed have been identified. These results form part of a project which has the aim of creating a framework for improving resilience assessment for isolated communities, with an initial focus on the West Coast region.

2. Introduction

Many isolated communities in New Zealand are significantly at risk from natural hazards and are also often dependent upon regional infrastructure (LGNZ, 2014, NIU, 2015). The New Zealand Government National Infrastructure Unit classifies New Zealand's infrastructure into six networks: transport, telecommunications, energy, three waters (potable water, waste water and storm waste), productive water and social infrastructure (including schools, hospitals, prisons, libraries, and swimming pools). Accordingly, infrastructure vulnerability affects risk in a number of ways, including service delivery, community preparedness, financial capabilities and organisational performance (NIU, 2015).

It is an implicit assumption within this study that isolated community risk is affected by regional hazards and infrastructure. For infrastructure with low or no redundancy, impacts at any point on the network can result in the remainder of the network becoming non-functional. For example, a landslide impacting a road can result in the entire section between junctions either side of the landslide becoming impassable, potentially resulting in large detours. Additionally, infrastructure networks are intimately interdependent, so impact to one service is likely to have cascading effects on other infrastructure (Buldyrev et al., 2010). Therefore, with increasing dependence upon regional infrastructure, risk is increasing for isolated communities; isolated communities are now not only significantly at risk of proximal natural hazards, but also of distal hazards that affect regional infrastructure (even if the community is not directly affected). Reducing infrastructure risk will, therefore, reduce community risk and reduce response and recovery times.

Infrastructure risk is the product of exposure and physical vulnerability. Infrastructure exposure is a measure of infrastructure and hazard colocation. Infrastructure vulnerability is a measure of infrastructure damage when impacted by a hazard (UNISDR, 2015). In this sense, exposure is viewed as a spatiotemporal attribute, and physical vulnerability an engineering attribute. Therefore, to reduce infrastructure risk, the first step is to assess the hazard and infrastructure exposure (Figure 53).

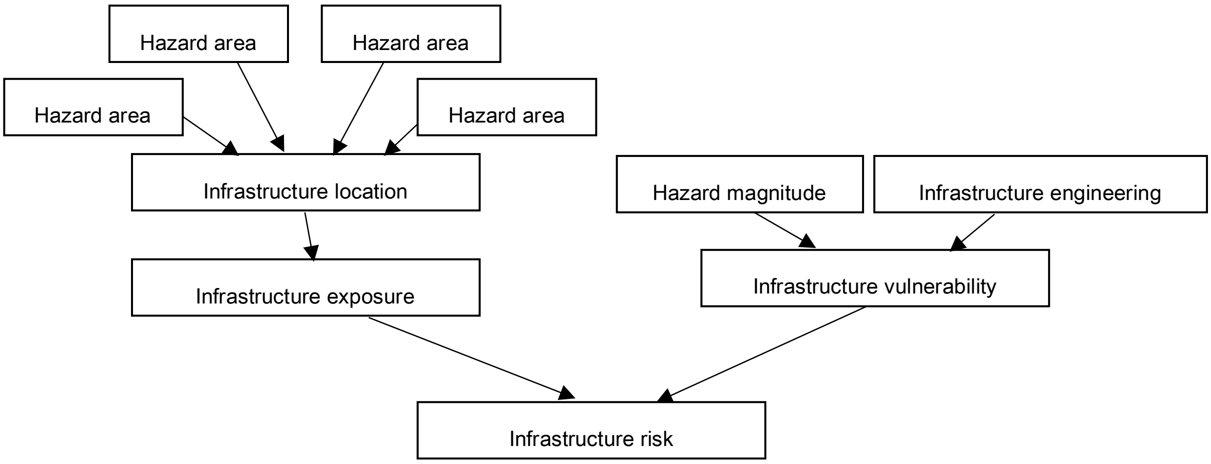

Figure 53. Conceptual framework.

A hazard is defined as something that has the potential to cause harm. Hazards interact in space and time and the possible interactions between hazards have been described using a large number of terms (see Kappes et al., 2012b). These can be distilled down into two types of multi-hazard interaction (after Saunders et al., 2015, Kappes et al., 2012a, Kappes et al., 2010, Carpignano et al., 2009, Kappes et al., 2012b): (i) Cumulative hazards are multiple, unrelated natural hazards that affect the same area; (ii) Cascading hazards are different types of hazard events that all result from the same trigger event. Once the trigger event occurs, the area will be subject to further hazard events. Cascading hazards include, but are not limited to, storm surges and flooding from hurricanes and typhoons, jökulhaups (glacial outburst floods) from sub-glacial volcanic eruptions, landslides and debris flows from mountainous earthquakes, and landslide dams and outburst floods from landslides (Robinson and Davies, 2013).

A commonality within both types of multi-hazard interaction is that one hazard can occur proximally to another hazard. If more than one hazard occurs within close spatial and temporal proximity, the hazard and/or impact magnitude may amplify to greater than the sum of the individual hazards (Kappes et al., 2010, Kappes et al., 2012a). Therefore, assessing hazards individually may underestimate risk, so it is critical to investigate multi-hazard interactions (Kappes et al., 2012b).

There is growing awareness of the need for multi-hazard assessment, especially for end-user adoption. A high percentage of land-use plans containing all-hazard objectives (Saunders *et al.*, 2015) and several sets of international guidelines and documents now advocate adoption of a multi-hazard approach to risk assessment, including the Sendai Framework for Disaster Risk Reduction, which dedicates multiple goals and states '[d]isaster risk reduction practices need to be multi-hazard and multi-sectoral, inclusive and accessible in order to be efficient and effective' (UNISDR, 2015, p. 10, Kappes et al., 2012b, Scolobig et al., 2013). However, significant differences in spatial and temporal resolutions, intensity, and measurement techniques mean hazards are (still) mostly assessed individually, resulting in hazard units which are not directly comparable (Kappes et al., 2012a, Marzocchi et al., 2012, Gill and Malamud, 2014).

Therefore, there is a clear need for a standardisation methodology. Two main standardisation approaches, hazard classification and indices, have been developed, although these are far from becoming common practice because so few studies have analysed multiple hazards (Kappes et al., 2012b). Hazard classification is the most frequently used multi-hazard standardisation approach. User-defined criteria create intensity and frequency thresholds which are used to classify hazards into qualitative categories (for example, high, medium and low hazard). While this is a simple way to compare hazards, every user's criteria and so classification are different, developed for different uses, meaning most qualitatively classified hazard datasets are not comparable (Kappes et al., 2012). Indices classify hazards independently, quantitatively standardising differing, not directly comparable parameters, allowing different datasets to be comparable. Indices also allow the difference between two hazard levels to be quantified (Kappes et al., 2012).

These attempts have first looked to make hazard magnitudes comparable. However, depending on the raw data format, this can be difficult to achieve. It is the impact of the hazard, rather than the hazard itself, that needs to be reduced in order to prevent (or reduce the consequences of) disasters (Glavovic et al., 2010). Therefore, this paper attempt to pioneer a new methodology to combine multi-hazard exposure as a first step towards multi-hazard risk assessment by first considering infrastructure exposure prior to magnitude or multi-hazard interactions.

3. Study area

The West Coast region of the South Island, New Zealand, is characterised by a number of natural hazards, including windstorms, earthquakes, rockfalls, landslides, debris flows, landslide dam-break flooding, river flooding, and tsunami. The West Coast region is also an iconic, rapidly developing tourist destination with numerous settlements, all of which can be considered isolated. These communities are reliant upon the region's linear road, electricity and communications infrastructure networks, which have no redundancy (outside townships) for over 400 kilometres. Despite this, no infrastructure risk assessment with a focus on the complete multi-hazard environment has been conducted for the West Coast region. This paper takes the first step towards completing such an assessment by conducting a multi-hazard exposure assessment for a section of the State Highway 6 (SH6), the primary road connection within the West Coast region (Figure 54).

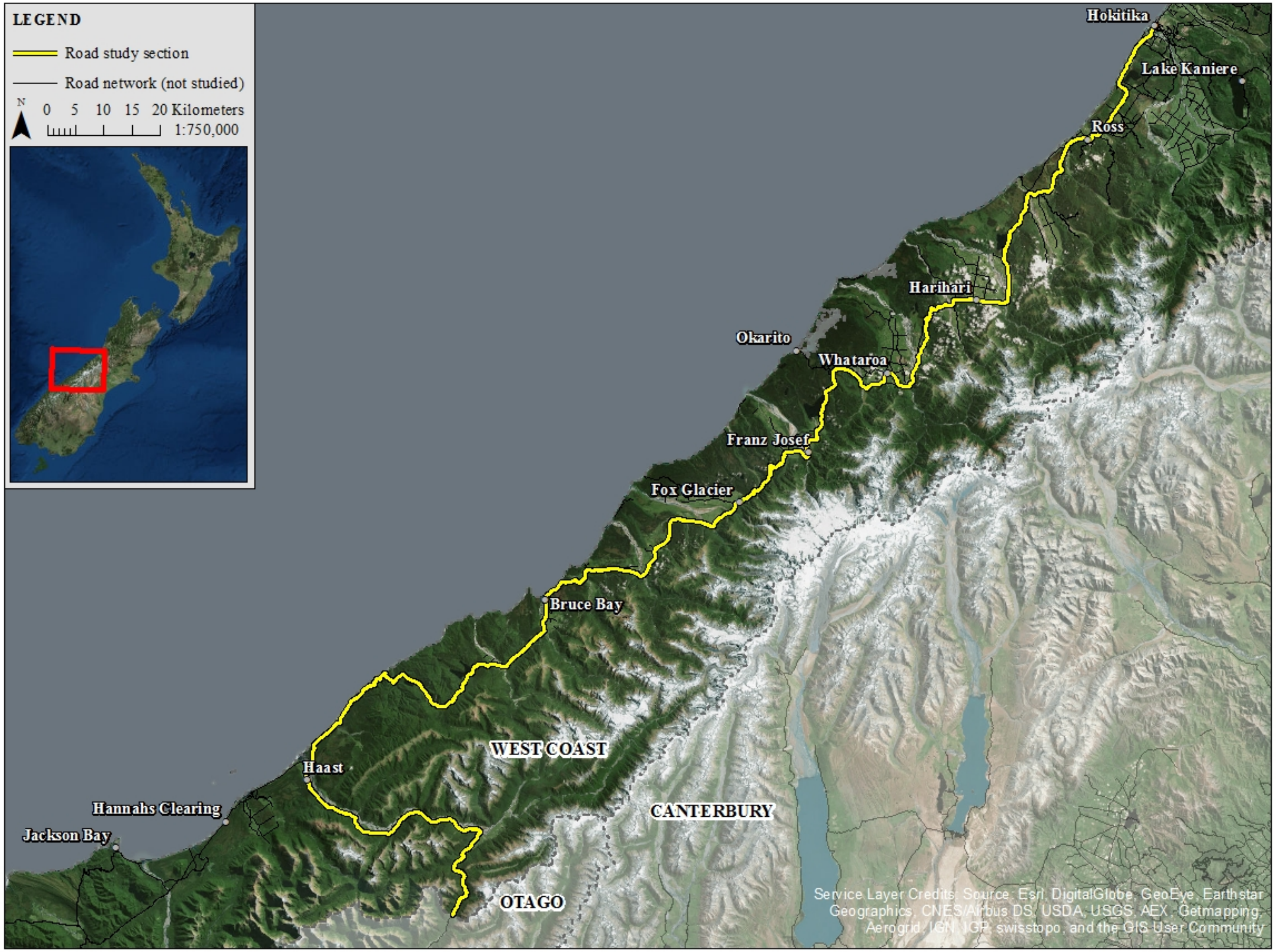

Figure 54. Map of the West Coast, New Zealand.

The studied section of State Highway 6 is shown in yellow and extends from Hokitika to the West Coast/Otago boundary in Haast Pass.

4. Methodology

This study aims to create a relative exposure assessment of SH6. Such an assessment highlights exposure “hotspots”: areas of the road network that are exposed to the most hazards. Currently this work does not take account of hazard intensity, hazard frequency, or the vulnerability of the road, and thus does not imply sections which are most likely (in a probabilistic sense) to be impacted, nor the most at-risk areas.

Existing hazard and susceptibility assessments for earthquake rupture, co-seismic landslides, rainfall-triggered debris flows and river floods, created by Kritikos (2013) and Robinson et al. (2015), were used as input data for the exposure analysis. These assessments limited the study area size to a 340 km stretch of SH6, between Hokitika and the West Coast-Otago regional boundary at Haast Pass (). Earthquake shaking and windstorm hazards were not used (as unique hazard inputs) because the respective hazard exposures were judged to be effectively uniform across the region. Tsunami exposure was not considered, although the majority of the road section studied is not thought to be exposed to tsunami (Power, 2013).

The hazards differ in their spatial extent and the existing hazard and susceptibility assessments were carried out independently, causing differences between the datasets. It is important to consider these differences, especially the spatial resolution of each assessment and scale used to describe the level of hazard, when attempting to combine the data. For example, surface ruptures have the ability to destroy a road, but are usually narrow and long, in terms of the two-dimensional area they affect. By sampling discrete points on the road (for example, every kilometre), a significant number of the small areas where the road is susceptible to the surface rupture hazard may be missed (especially when you consider the road can run perpendicular to a fault). A similar spatial issue arises for debris flow exposure. So, to allow the datasets to be combined, the road network was divided into 1 km sections (the road was assumed to be 10 metres wide), and values were attributed to each of these sections using GIS software for each hazard, as explained below:

4.1 Earthquake rupture

Earthquake rupture was derived from the New Zealand Active Faults Database (GNS, 2016). Buffers of 50 m, 100 m and 500 m from known faults were added to account for known and potential errors in fault mapping. These were attributed exposure values of 0.9, 0.5 and 0.1 respectively. Each 1 km section was then subsequently awarded the highest observed exposure value for that section. For example, if a 1 km section of road came within 100 m of a fault at one point and within 50m of a fault at another point, the section was given an exposure value of 0.9.

4.2 Landslide

Landslide exposure was calculated according to Robinson et al. (2015), which calculated coseismic landslide exposure values for a modelled M_w 8.0 earthquake on the Alpine Fault, assuming landslide runout direction is in the steepest downhill direction. This technique resulted in point outputs at 1 km intervals along the network. These point values were spatially interpolated along the road. Subsequently, the highest exposure value within each kilometre section of road was attributed to the entire kilometre.

4.3 Debris flow

Rainfall-triggered debris flow susceptibility was calculated by Kritikos (2013). The raster output from these calculations (which was categorised into classes of susceptibility from 1 to 5) was used for this study. The highest value within the kilometre section was attributed to the entire kilometre. These values were then normalised in order to retain a consistent 0 - 1 exposure scale with the other considered hazards.

4.4 River flooding

River flooding susceptibility was calculated by Kritikos (2013). The raw raster output from these calculations was used for this study. The highest exposure value within the kilometre section of road was attributed to the entire kilometre.

The highest exposure value within each kilometre section of road was attributed to the entire kilometre because the aim of this study is to highlight the sections of road which have high exposure values. The multi-hazard exposure assessment for each 1 km section of road was then produced by calculating the mean hazard exposure of the four considered hazards. It is acknowledged that it is impossible to be certain of exposure values, but for simplification within the individual hazards calculations, some data were attributed values of zero or one. No data had exposure values of zero or one in the final multi-hazard exposure assessment.

5. Results

The landslide, river flood and combined hazards results, which comprise continuous hazard exposure data, were categorised into six discrete bins (0.0, $0.0 > x < 0.2$, $0.2 \geq x < 0.4$, $0.4 \geq x < 0.6$, $0.6 \geq x < 0.8$, $0.8 \geq x < 1.0$) in order to allow direct comparisons with the surface rupture and debris flow hazard exposures.

5.1 Results tables and exposure maps

The results are displayed below, in terms of total length of road (km) corresponding to each exposure bin. Exposure maps for earthquake rupture, landslide, debris flow and river flood (Figure 55) and combined hazards (Figure 56) along the SH6 study section are presented on the following pages.

Table 8. Earthquake rupture exposure.

Exposure Value	Length of road (km)
0.0	299
0.1	22
0.5	4
0.9	15

Table 9. Debris flow exposure.

Exposure Value	Length of road (km)
0.0	222
0.2	0
0.4	8
0.6	59
0.8	31
1.0	20

Table 10. Landslide exposure.

Exposure Value	Length of road (km)
0.0	0
0.0 > x < 0.2	177
0.2 ≥ x < 0.4	156
0.4 ≥ x < 0.6	7
0.6 ≥ x < 0.8	0
0.8 ≥ x < 1.0	0

Table 11. River flooding exposure.

Exposure Value	Length of road (km)
0.0	75
0.0 > x < 0.2	1
0.2 ≥ x < 0.4	16
0.4 ≥ x < 0.6	45
0.6 ≥ x < 0.8	62
0.8 ≥ x < 1.0	141

Table 12. Combined hazards (earthquake rupture, landslide, debris flow and river flooding).

Exposure Value	Length of road (km)
0.0	0
0.0 > x < 0.2	80
0.2 ≥ x < 0.4	198
0.4 ≥ x < 0.6	58
0.6 ≥ x < 0.8	4
0.8 ≥ x < 1.0	0

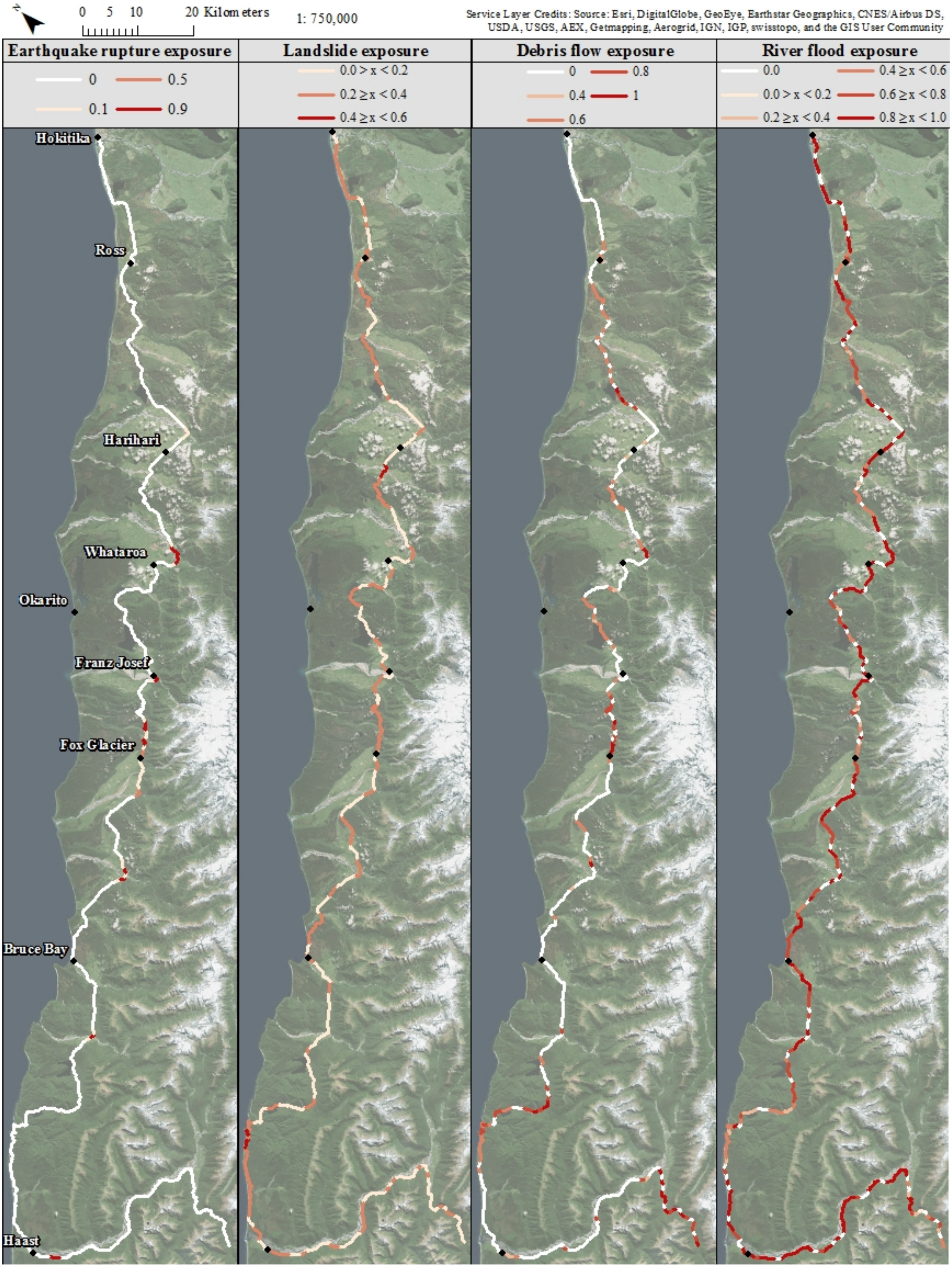

Figure 55. SH6 earthquake rupture, landslide, debris flow and river flood exposures.

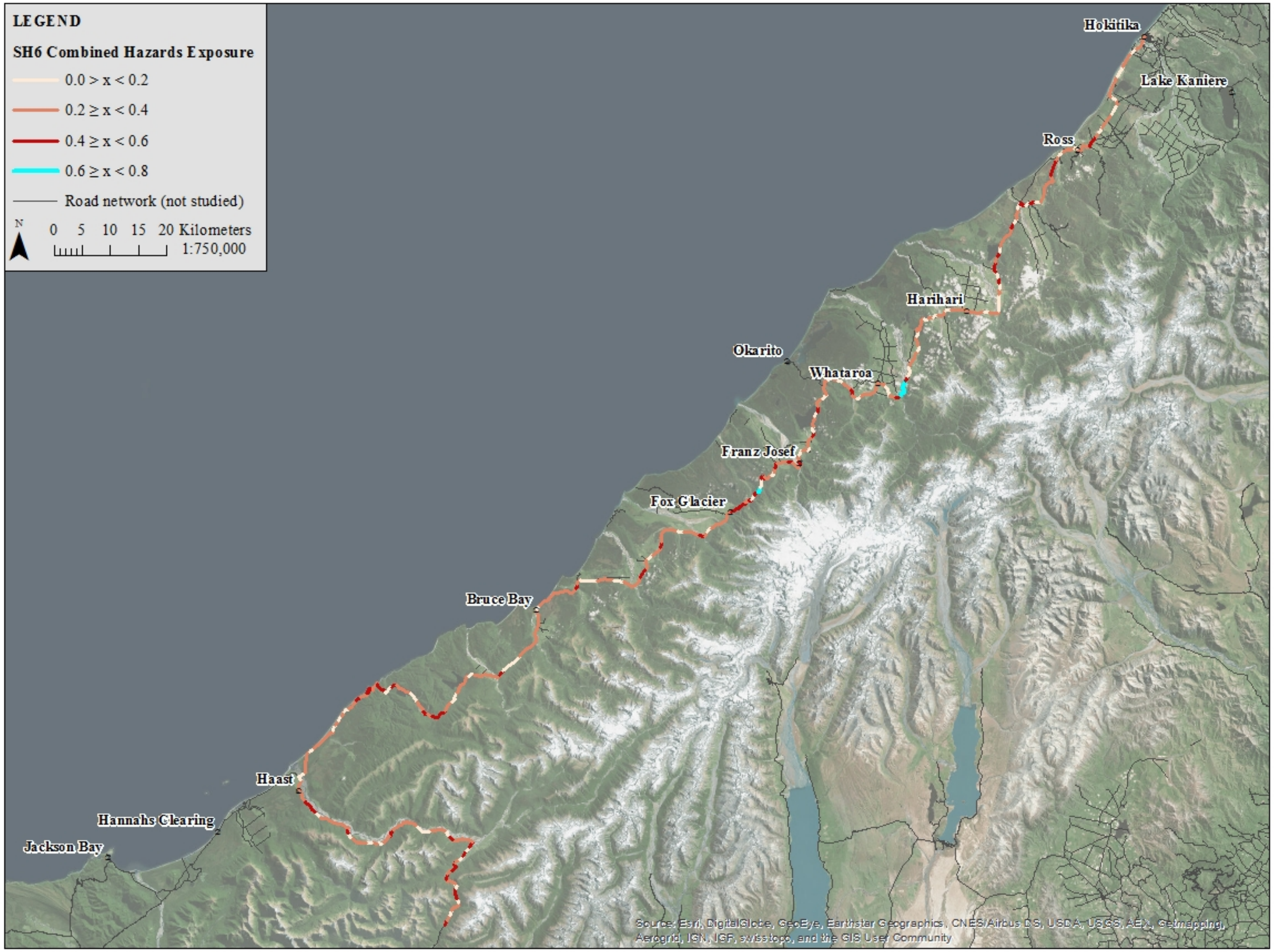

Figure 56. SH6 combined hazards (earthquake rupture, landslide, debris flow and river flood) exposure.

6. Discussion

The results highlight significant differences in exposure between the hazards. As expected, the majority of road sections are not exposed to earthquake rupture, nor debris flow, as these are localised hazards. The four individual hazard maps (Figure 55) also clearly show the road has highest exposure to river flooding; over 40 percent of the road sections are categorised into the highest river flooding exposure range, between $0.8 \geq x < 1.0$ (Table 11). Finally, although the landslide hazard is the only hazard all road sections have an attributed exposure value for, the landslide hazard has the smallest exposure range, with no road sections attributed exposure values greater than 0.59 (Table 10). The combined exposure values (Figure 56) differ significantly from each of the individual hazards exposure values but also suggest hazard exposure is not random: few road sections with the highest hazard exposure values are situated immediately next to sections with the lowest exposure values.

The results reflect the influence of the regional geomorphology upon hazard exposure, which is also amplified in the combined exposure values. The individual debris flow and flood hazard maps (Figure 55) show high river flood and debris flow exposure values are spatially coincident. The four sections of road with the highest combined exposure values (over 0.6) evidence this spatial coincidence; three of the four sections have a debris flow exposure value of 1.0 (one section has a debris flow exposure value of 0.6) and three of the four also have a flood exposure value of over 0.9 (the other section has a flood exposure value of 0.34). Each of these road sections also had the highest surface rupture exposure value of 0.9, but none of the four sections were also among the four highest landslide exposure sections (values over 0.4), with values instead ranging between 0.15 and 0.23.

The road sections have lower landslide exposure values largely because of the position of the road within the regional geomorphology and hazardscape. Although there is a lower range of landslide hazard exposures along the road, the West Coast landslide exposure range is equitable within the West Coast as a whole. Put simply, roads are not built along the tops of mountains, where the highest landslide exposure values are usually found. Therefore, purely as a result of topographic preferences within road building, high landslide exposure values are less common along the studied section of SH6 than high flood exposure values; the lower landslide exposure values are a reflection of coincidental hazard management: if the road was moved higher up the mountains, landslide exposure would increase.

With the road in its current position, the most exposed sections are located either side of Franz Josef, Okarito and Whataroa. This analysis suggests these sections of road are most exposed to hazards. However, without vulnerability information, including hazard magnitude, this study is unable to state the sections of road which are most at risk to natural hazards.

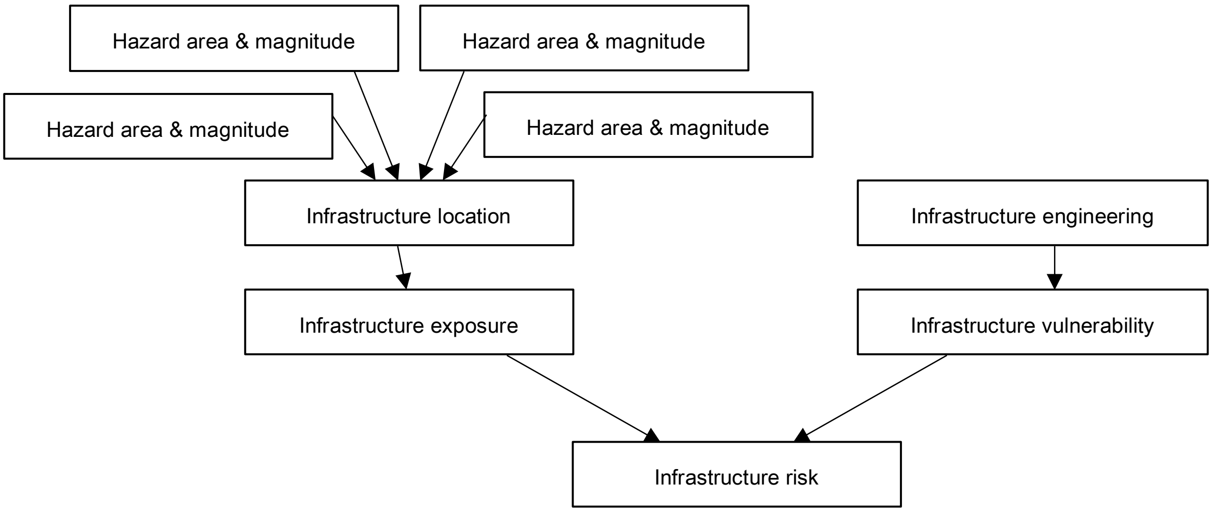

Figure 57. Revised conceptual framework.

It is difficult to envisage how to include a vulnerability assessment following the decoupling of hazard exposure and hazard magnitude. Furthermore, it is uncertain how (relative) exposures should be calculated in order to make them comparable for a region: because relative exposure values from independent analyses have been used, the landslide, debris flow and river flooding exposures may also have been distributed differently and this may have affected their weighting within the combined exposure data. Given these observations, it is unlikely this method will be useful to reach the goal of multi-hazard risk assessment. Combining all information on each individual hazard first (including hazard magnitude), before assessing infrastructure vulnerability to each hazard and aggregating this work, is more likely to be a successful strategy for infrastructure multi-hazard risk assessment (Figure 57).

7. Conclusions

It is clear that this combined hazards exposure assessment (Figure 56) differs significantly from the individual hazard exposure assessments (Figure 55) and regional geomorphology has a significant influence upon hazard exposure. The results show that in its current position, the road has lower exposure to landslides. The effect of the regional geomorphology on the hazards also amplifies hazard exposure where the road crosses river channels, as both the river flood and debris flow hazards are channelised.

The results show the most exposed sections of road are located either side of Franz Josef, Okarito and Whataroa, meaning these settlements are most exposed to hazards impacting road access along the study section. However, by de-coupling hazard magnitude, it is impossible to infer any sense of the risk the multi-hazard environment presents to the West Coast infrastructure, and so to the isolated communities it serves.

It is difficult to envisage how to include a vulnerability assessment following the decoupling of hazard exposure and hazard magnitude. Therefore, it is unlikely this method will be useful to reach the goal of multi-hazard risk assessment. Combining all information on each individual hazard (including hazard magnitude), before assessing infrastructure vulnerability to each hazard and aggregating this work, is more likely to be a successful strategy for infrastructure multi-hazard risk assessment.

Nevertheless, this paper offers a useful first multi-hazard exposure assessment for State Highway 6 on the West Coast of New Zealand. The multi-hazard exposure map (Figure 56) shows numerous hazard “hotspots” which, if are significantly vulnerable, could cause significant disruption for isolated communities which are reliant upon this regional infrastructure.

8. References

Buldyrev, S. V., Parshani, R., Paul, G., Stanley, H. E. and Havlin, S. (2010) 'Catastrophic cascade of failures in interdependent networks', *Nature,* 464(7291), pp. 1025-1028.

Carpignano, A., Golia, E., Di Mauro, C., Bouchon, S. and Nordvik, J. P. (2009) 'A methodological approach for the definition of multi-risk maps at regional level: first application', *Journal of Risk Research,* 12(3-4), pp. 513-534.

Gill, J. C. and Malamud, B. D. (2014) 'Reviewing and visualizing the interactions of natural hazards', *Reviews of Geophysics,* 52(4), pp. 680-722.

Glavovic, B. C., Saunders, W. S. A. and Becker, J. S. (2010) 'Land-use planning for natural hazards in New Zealand: the setting, barriers, ‐ burning issues‐ and priority actions', *Natural Hazards,* 54(3), pp. 679-706.

GNS (2016) 'New Zealand Active Faults Database'. Available at http://data.gns.cri.nz/af/. Accessed: 24/04/2016.

Kappes, M., Keiler, M. and Glade, T. 'From single-to multi-hazard risk analyses: a concept addressing emerging challenges'. *Proc Int Conf on Mountain Risks: Bringing Science to Society, Firenze, Italy*.

Kappes, M., Papathoma-Köhle, M. and Keiler, M. (2012a) 'Assessing physical vulnerability for multi-hazards using an indicator-based methodology', *Applied Geography,* 32(2), pp. 577-590.

Kappes, M. S., Keiler, M., von Elverfeldt, K. and Glade, T. (2012b) 'Challenges of analyzing multi-hazard risk: a review', *Natural Hazards,* 64(2), pp. 1925-1958.

Kritikos, T. (2013) 'Geomorphic Hazard Analyses in Tectonically-Active Mountains: Applications to the Western Southern Alps, New Zealand', *PhD Thesis*.

LGNZ (2014) 'Managing natural hazard risk in New Zealand - towards more resilient communities'. Available at http://www.lgnz.co.nz/assets/Publications/Managing-natural-hazards-LGNZ-think-piece.pdf. Accessed 24/04/2016.

Marzocchi, W., Garcia-Aristizabal, A., Gasparini, P., Mastellone, M. L. and Di Ruocco, A. (2012) 'Basic principles of multi-risk assessment: a case study in Italy', *Natural hazards,* 62(2), pp. 551-573.

NIU (2015) 'The Thirty Year New Zealand Infrastructure Plan 2015'. Available at http://purl.oclc.org/nzt/i-1785. Accessed: 24/04/2016.

Power, W. (2013) 'Review of tsunami hazard in New Zealand (2013 update)', *GNS Science Consultancy Report 2013,* 131, pp. 222.

Robinson, T. and Davies, T. (2013) 'Review article: Potential geomorphic consequences of a future great (M w= 8.0+) Alpine Fault earthquake, South Island, New Zealand', *Natural Hazards and Earth System Science,* 13(9), pp. 2279-2299.

Robinson, T. R., Davies, T. R., Wilson, T. M., Orchiston, C. and Barth, N. (2015) 'Evaluation of coseismic landslide hazard on the proposed Haast-Hollyford Highway, South Island, New Zealand', *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, pp. 1-18.

Saunders, W., Grace, E., Beban, J. and Johnston, D. (2015) 'Evaluating Land Use and Emergency Management Plans for Natural Hazards as a Function of Good Governance: A Case Study from New Zealand', *International Journal of Disaster Risk Science,* 6(1), pp. 62-74.

Scolobig, A., Garcia-Aristizabal, A., Komendatova, N., Patt, A., Di Ruocco, A., Gasparini, P., Monfort, D., Vinchon, C., Bengoubou-Valerius, M. and Mrzyglocki, R. (2013) 'From Multi-Risk Assessment To Multi-Risk Governance: Recommendations for Future Directions'.

UNISDR (2015) 'Sendai Framework for Disaster Risk Reduction 2015-2030'. Available at http://www.unisdr.org/we/coordinate/sendai-framework. Accessed 24/04/2016.

Appendix B. Increasing communities' resilience to disasters; an impact-based approach

Tim R. H. Davies[1], Alistair J. Davies[1]

[1] University of Canterbury, Christchurch, New Zealand.

Journal: International Journal of Disaster Risk Reduction

Submitted: May 2018

Revised: July 2018

Accepted: July 2018

Online: July 2018

Published: Vol. 31, October 2018

1. Abstract

The conventional processes of science, and the incorporation of science into policy and practice, appear not to be resulting in improved disaster reduction solutions for communities, despite intense research into hazards and risk. Resilience to disasters is increased when the societal impacts of disasters are reduced. On this basis, the contribution that Disaster Risk Reduction (DRR) can make to Disaster Impact Reduction (DIR) is assessed, and it is demonstrated that reducing event risk by reducing event probability only reliably reduces community disaster impacts for events that occur frequently. Such events do not fit the UNISDR definition of a disaster. Therefore, DRR cannot reliably improve DIR. Instead, DIR can be addressed directly by way of community adaptation, based on carefully selected impact scenarios derived by community-expert-official collaborations considering a broad range of event and asset damage scenarios. Probabilistic risk is a useful tool in insurance and re-insurance, and possibly in national policy-making, but such national policies are likely to be undermined by inevitable failures of risk-based approaches at the local level. This work clarifies the common usage of "risk" as meaning either impact, or impact x probability.

2. Introduction

Well into the 21st century, society is still attempting to come to grips with its ever-increasing vulnerability to extreme events resulting from the natural processes of planet Earth. This vulnerability has recently been demonstrated by extreme naturally-triggered disasters such as the 2004 Indian Ocean tsunami (e.g. Chatenoux and Peduzzi, 2007), the 2011 Tohoku earthquake-tsunami (e.g. Mochizuki, 2014) and hurricane Harvey in 2017 (e.g. Shuckburgh et al., 2017).

Over the last few decades, the global policy and research community has come together several times to progress the task of reducing the impacts of disasters on society. This challenge was first taken up at the 2005 UN World Conference on Disaster Reduction (WCDR) in Kobe, Japan, only days after the 2004 Indian Ocean tsunami. International agencies and national governments then began to move toward setting clear targets and commitments for disaster reduction. The first step in this process was the formal approval, at the World Conference on Disaster Reduction, of the Hyogo Framework for Action (HFA: 2005–2015). The World Conference on Disaster Risk Reduction held on March 14–18, 2015, in the Japanese city of Sendai, adopted the successor accord to the Hyogo Framework. It is known as the Sendai Framework for Disaster Risk Reduction (2015-2030; https://www.unisdr.org/we/coordinate/sendai-framework). The global policy and research area by means of which nations are attempting to reduce vulnerability is thus "Disaster Risk Reduction" (DRR: e.g. Aitsi-Selmi et al., 2015).

While less prominent in the official rhetoric, resilience has become a key concept in promulgating vulnerability reduction worldwide during the present century (e.g. Paton and Johnston, 2017). Compared to DRR, the term resilience conveys better to non-experts the concept that they can be less affected by future disasters if they can become "resilient". The term conveys a sense of merit in the context of disasters, in much the same way that "sustainability" implies environmental merit.

Accordingly, a number of research and operational initiatives worldwide presently focus on resilience to disasters: for example, the New Zealand National Science Challenge "Resilience to Nature's Challenges"; the establishment of Durham University (UK)'s Institute for Hazard, Risk and Resilience; the National Disaster Resilience Strategy under development by the Ministry of Civil Defence & Emergency Management, New Zealand (Ministry of Civil Defence & Emergency Management, 2018); the Queensland Strategy for Disaster Resilience, Australia (Queensland Government, 2014); and the Los Angeles County Community Disaster Resilience Project, USA (Rand Corporation,2018).

The substantial effort among global agencies to try to mitigate disaster effects has been matched by plentiful academic discussions and analyses of both "DRR" and "resilience". While DRR appears to be the better defined and understood term, perhaps because of its relationship with the well-established discipline of Risk Management (e.g. Twigg, 2004; ISO 31000, 2009), clarity in the usage and meaning of "resilience" is less evident. The ongoing detailed academic debate and discussion are not currently showing clear signs of converging to an agreed set of concepts usable in practice. Meanwhile, naturally-triggered disasters are exacting ever-increasing societal costs (https://www.preventionweb.net/risk/trends, accessed 19 May 2018).

The purpose of the present work is, therefore, to propose some pragmatic short-cuts through these detailed academic considerations and, recognising from an operational perspective the need for urgency in community planning to reduce the effects of future disasters, to develop a set of feasible activities that can begin to improve communities' resilience to these events. Real-life disaster situations involve intricate and complex societal and political factors that may substantially affect the processes we suggest below. However, we do not believe that these complexities invalidate our analysis or suggestions.

First, we present the global high-level definitions relating to DRR and resilience. Second, we make the case that, however it is defined, resilience is increased if the impacts of future disaster events on society are reduced (Disaster Impact Reduction, DIR). On this basis, we show that DRR only increases resilience for events that occur many times in the planning timeframe of a community. These frequent events do not fit the UNISDR definition of a disaster. For events that match definitions of disasters (occurring very few times in a planning timeframe), DRR does not reliably lead to DIR, and therefore does not reliably lead to increased resilience.

Acknowledging that DRR does not necessarily lead to DIR, we consider DIR itself as the basis of increasing resilience as an alternative - or complement - to DRR. We suggest ways communities can identify and undertake adaptations that will result in reduction of the impacts of future disasters. These involve the use of disaster impact scenarios, rather than (or as a complement to) the annualised damage cost and net benefit estimates that often underpin risk-based decision support tools.

3. Terminology

Since the following discussion examines the relationships between DRR and resilience, we now summarise the definitions of these terms, as promulgated by UNISDR (2017); (italics added for emphasis).

3.1 Disaster

A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.

Annotations: The effect of the disaster can be immediate and localized, but it often widespread and could last for a long period of time. The effect may test or exceed the capacity of a community or society to cope using its own resources, and therefore may require assistance from external sources, which could include neighbouring jurisdictions, or those at the national or international levels.

3.2 Disaster risk

The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.

3.3 Disaster risk reduction

Disaster risk reduction is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development

3.4 Resilience

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.

The italicised phrases in these definitions correspondingly imply:

(a) that a disaster is unlikely to result from an event that happens more frequently than once every ten to twenty years, simply because the affected community will remember the recurrence of such events and will adapt (plan for them) so as to be less affected by them, in the knowledge that they will recur in the future; therefore, they are unlikely to be serious.

(b) That risk is determined probabilistically, meaning that risk of event = probability of event x consequence of event,

(c) that risk reduction results in resilience, and
(d) that resilience is achieved through risk reduction (management).

It is important to recognise that there are numerous definitions of these terms within the wider literature; the UNISDR definitions are not ubiquitous. This piece focusses on the terms “disaster” and “resilience”. Therefore, further definitions of these terms are provided and discussed below.

3.5 Other definitions

Other definitions of “disaster” (cited by Kelman, 2017) include:

- EMA (1998). “A serious disruption to community life which threatens or causes death or injury in that community and/or damage to property which is beyond the day-today capacity of the prescribed statutory authorities and which requires special mobilisation and organisation of resources other than those normally available to those authorities.”
- FEMA, 2004 “An occurrence of a natural catastrophe, technological accident, or human caused event that has resulted in severe property damage, deaths, and/or multiple injuries.” http://www.fema.gov/pdf/rrr/glo.pdf on 8 July 2004.
- Reliefweb (2008) “A serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources.”
- UN DHA (1992) “A serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the ability of affected society to cope using only its own resources. Disasters are often classified according to their cause (natural or manmade).”

From these additional definitions, it is clear that a common concept within definitions of “disaster” is the inability of the local community to manage the event using its own resources. This signifies the severity required to term an event a disaster and also implies the relatively infrequent occurrence of such events in a given locality.

Examples of other “resilience” definitions include (italics added for emphasis):

- IPCC (2012): “The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.”
- DFID (2011): “the ability of countries, communities and households to manage change, by maintaining or transforming living standards in the face of shocks or stresses – such as earthquakes, drought or violent conflict – without compromising their long term prospects.”

The above definitions thus unequivocally imply that resilience to disasters can be achieved by risk reduction. This implication is examined more closely herein.

4. Disasters

Genuine disaster events are, as defined above (Section 3), rare in any specific location, and often (in fact, usually; Davies, 2015) unexpected. Less frequent events are less likely to be present in societal memory, so are less expected, and pre-adaptation to their impacts is less likely. Definitions commonly imply that a disaster is unlikely to result from an event that happens more frequently than once every ten to twenty years, simply because the affected part of society will remember the recurrence of such events and will adapt (plan for them) so as to be less affected by them, in the knowledge that they will recur in the future. Therefore, events that occur at a range of frequencies, but are common enough to be expected, do not fit definitions of a disaster.

5. Resilience

In the disaster context, the term "resilience" first came into use in the 1950s (one article reported in Scopus); by 1990, seven articles were reported; by 2000, 40; by 2010, 770; and by 2018, almost 5000. This rapid growth in usage has been accompanied by a plethora of definitions of the term – Scopus currently reports 151 articles including the terms "disaster resilience" and "definition". This suggests that the term "disaster resilience" is widely used for a range of concepts, which in turn makes it difficult to operationalise in practice. How does one develop strategies that will lead to resilience when controversy (if not confusion) exists over its meaning? This is particularly difficult when working with communities whose members are unlikely to be familiar with any technical interpretation of the word.

Here, we adopt the UNISDR (2017) interpretation of resilience quoted above (Section 3), excluding the final phrase; we question both the UNISDR (2017) and IPCC (2012) definitions for their emphasis on "the preservation and restoration of… essential basic structures and functions" and "ensuring the preservation of basic structures and functions" when these very structures and functions may cause vulnerability. Instead, we interpret these definitions as supporting the societal preference for business as usual (especially given the IPCC definition also notes the option of improving structures and functions). Somewhat similarly, the DFID (2012) definition focuses on "maintaining or transforming living standards" in the face of disaster; when it is appreciated that a large proportion of Earth's population suffer poor living standards and struggle to "maintain or transform" them in the absence of disasters, this appears optimistic.

The objective of the present work is to propose a set of strategies that will realise "disaster resilience" for a community (in the present context, a self-identifying spatially-localised group of people; e.g. a town, or village, or region). Why would a community want to achieve resilience to disasters? Often, because many people in the community are aware that disasters can befall them in the future, and they want a plan that will enable the community to survive these disasters and redevelop prosperity afterwards; the alternative is to ignore the prospective disasters and accept the greater costs that will result. While some community members may be psychologically inclined to the alternative way of thinking (able to put the potential catastrophes out of mind while hoping that no disaster will occur in their lifetime), other community members will be inclined to the former, and their lives would be substantially improved if there were a plan that enabled them to see confidently past a disaster to a future with a good quality of life. More pragmatically, external organisations will be much more likely to invest in a community that plans for future disasters than in one that does not.

5.1 Achieve resilience or increase resilience?

Most of the definitions referred to above see resilience as something that can be achieved if the right things are done. However, it is difficult to ascertain whether or not anything is resilient until it is clear what it needs to be resilient to. In the disaster context, this is obviously disasters – but which disasters? Disasters come in a wide range of types and intensities; it is clearly unrealistic to achieve complete resilience to all of them, so in reality a community has to make a choice about how resilient it wishes to become – and to which disasters. This clarifies the issue somewhat; there are degrees of resilience, it is not a binary quality. Hence, resilience can perhaps better be seen as a direction that will lead towards improved "ability… to resist, absorb, accommodate…" (UNISDR, 2017, Section 2d) and so on, rather than as a well-defined state which can be achieved once and for all. This view accords with that of Manyena (2006), who argues strongly "… for a process-oriented definition of resilience, saying that [t]he danger of viewing disaster resilience as an outcome is the tendency to reinforce the traditional practice of disaster management, which takes a reactive stance." (Gilbert, 2016). In a similar vein, Pelling (2012) approaches resilience (to climate change) as an outcome of the processes of adaptation and transformation that derive from identification of the basic causes of vulnerability as consequences of dominant development policies.

5.2 More resilient to what?

This is the other key question. The crucial phrase in the UNISDR definition (Section 2d) is "effects of a hazard" (emphasis added); this is what the achievement of resilience will reduce, and this is what the community needs to achieve resilience to. A community may be vulnerable to a range of potential disasters, such as earthquakes, landslides, flooding, etc., all of which behave differently, some of which can be forecast shortly in advance and some of which cannot. However, it is not the event itself to which the community needs to become more resilient; it is the "effects" (Section 2d) or impacts of the event on the community's ability to go about its normal business. These impacts involve damage to assets (houses, commercial premises, critical infrastructure, lifelines), damage to people (deaths and injuries) and interruption of services (food and fuel supply, health and welfare provision, civil order). Whichever kind of event hits the community, these are the impacts to which improved resilience is required. Every community will be uniquely vulnerable to these impacts because of its unique combination of sociocultural and socioeconomic make-up and physical location.

A community will evidently be more resilient to the impacts of any given hazard event if those impacts can be reduced; thus, a direct route to improved resilience to disasters is by way of measures to reduce the impacts of disasters on the community. Many years of experience have demonstrated that attempts to modify or prevent the hazard itself are unreliable, and can make impacts worse (e.g. Criss and Shock, 2001; Supprasi et al, 2013; Mileti and Gailus, 2005); hence the measures required to reduce impacts need to look at modifying society and its behaviour, to increase resilience to disaster events.

5.3 Costs of resilience

Resilience to disasters is not a free good, because investment in disaster resilience means less investment somewhere else. Every community has a range of vulnerabilities; for example, to everyday commercial competition as well as to natural events, and to occasional hazard impacts as well as genuine disasters (Section 4). Increased investment in resilience to disaster impacts may evidently reduce investment in everyday commerce and in protection against occasional hazard events (Ulanowicz et al., 2009). Thus, any decision to prioritise investment in disaster resilience over other vulnerabilities to any given degree has to be taken by the community itself, as it is the body that is vulnerable, that has a clear picture of its desired future and has to pay for disaster resilience (Pearce, 2003). Here, we are focussed on reducing impacts of future hazard events which, if occurred today, would be disastrous. Therefore, this ignores the reality that reactional response to, and recovery from, any serious disaster are likely to be government-funded, because such retrospective assistance is known to be less effective and less beneficial for the community than pre-planned disaster resilience (UNISDR, 2005).

5.4 Resilience in a nutshell

From the above, we conceptualise "disaster resilience" for present purposes as: societal adaptation designed to reduce the impacts of future disaster events on the everyday life of the community to an extent commensurate with the wishes of the community. Note that this definition is not exclusive; other measures, such as preparation for disaster response and recovery, which do not directly reduce impacts, also lead to increased resilience. Nevertheless, even these measures indirectly reduce impacts because they speed the achievement of post-disaster conditions.

6. Planning timeframe

It is important to consider the future time period for which the community can sensibly plan, for two main reasons:

1. The farther into the future we try to plan, the more difficult it is to imagine how the community will have altered due to societal changes. For example, if we contemplate planning for 100 years into the future, we need to be able to visualise what 22nd century society will be like; this depends on many poorly-known factors such as how much sea level rise will have occurred and the impact this will have had on global society, the number and nature of wars that may have occurred, the nature of technology, global population and so on. For comparison, imagine someone in 1918 trying to plan for the world in 2018.

2. The longer in the future we plan for, the greater the number of hazard events that will affect the community in that time, on average. Curiously, as we shall see, the greater the number of hazard events we are concerned with, the greater is the reliability with which we can predict their future occurrence.

The second factor suggests that considering a long future planning period is advantageous, but the first obviously limits the feasibility of long-term planning. Since, in Western society at least, we can realistically assume that:

- adult individuals' serious interest in the future of the community they currently live in likely extends at most to 50 years (perhaps increased to 100 if they expect their children and grandchildren to stay in the same community);
- political planning and policy horizons rarely extend beyond 10-20 years;
- buildings and infrastructure rarely have expected lives greater than 50-100 years; and that
- plans are superseded on a rolling basis and thus evolve with time,
- then planning is realistically limited to 50 – 100 years, at most. In the present work we take 100 years as the future period of interest, both for simplicity and to acknowledge that, although a shorter period may be more realistic, planning horizons lack clarity.

Further, acknowledging that any disaster will, by definition, have serious impacts on a community, it is reasonable to infer that the way a community redevelops after a disaster will result in significant changes to the pre-disaster situation. The nature of these changes is extremely difficult to anticipate, so the impacts of a further disaster on the changed community cannot be foreseen. Thus, after a disaster, the resilience plan will need to be revisited to take account of these changes.

Hence the relevant and realistic planning time frame for a community is either until the next disaster, or for 100 years, whichever is the shorter.

7. To what extent does DRR imply DIR?

As noted above (Section 3.2), risk is defined as the product of event probability and event consequence. For present purposes, consequence is equated with impact (i.e. risk is defined as the product of event probability and event impact); that is, consequence and impact both describe the costs to the community of the event resulting from damage to assets, lifelines, infrastructure, deaths and injuries, together with the consequential short-and long-term societal and commercial disruption.

Given a planning timeframe of a century (Section 6), the total impact on the community of specific future disaster events is the number of events that occur in that time multiplied by the average cost per event. The number of events in a century is 100 times the annual event probability, so on this basis, measures that reduce risks by reducing probability will indeed reduce the total impacts of those events by reducing the number of events that occur.

This assumes, however, that the number of events that will occur in any given 100-year period is accurately represented by the event probability. This is not necessarily – or even usually – the case.

For example, if the annual event probability is 0.500, then the number of events in any given 100 years will theoretically be exactly 50, but in reality will be roughly 50 – it is likely to be within the range of 40-60 or so, but in terms of assessing costs 50 is close enough, especially considering that these are relatively low-impact events.

Considering rarer, more intense events, however – say with an annual probability of 0.05 – then the number of events in the next 100 years may realistically be 3, or 4, or 5, or 6, or 7, compared with the theoretical number of 5. In this case it makes a large difference to total impacts if 3 events occur or 7 events occur (Figure 58).

Further, using an example that the probability of such events is reduced from 0.050 to 0.030 through hazard mitigation, while the event impacts stay the same; now the number of events may be 1, or 2, or 3, or 4, or 5. Hence, although the risk has been reduced by 40%, and the total impact may indeed be reduced, it may not – there is a 30% chance it will the same or greater. Thus, although reducing the risk by 40% may reduce the number of occurrences, there is no guarantee of this. This means that, in general, there is no guarantee that reducing risk by reducing probability will in fact reduce total impact (Figure 58).

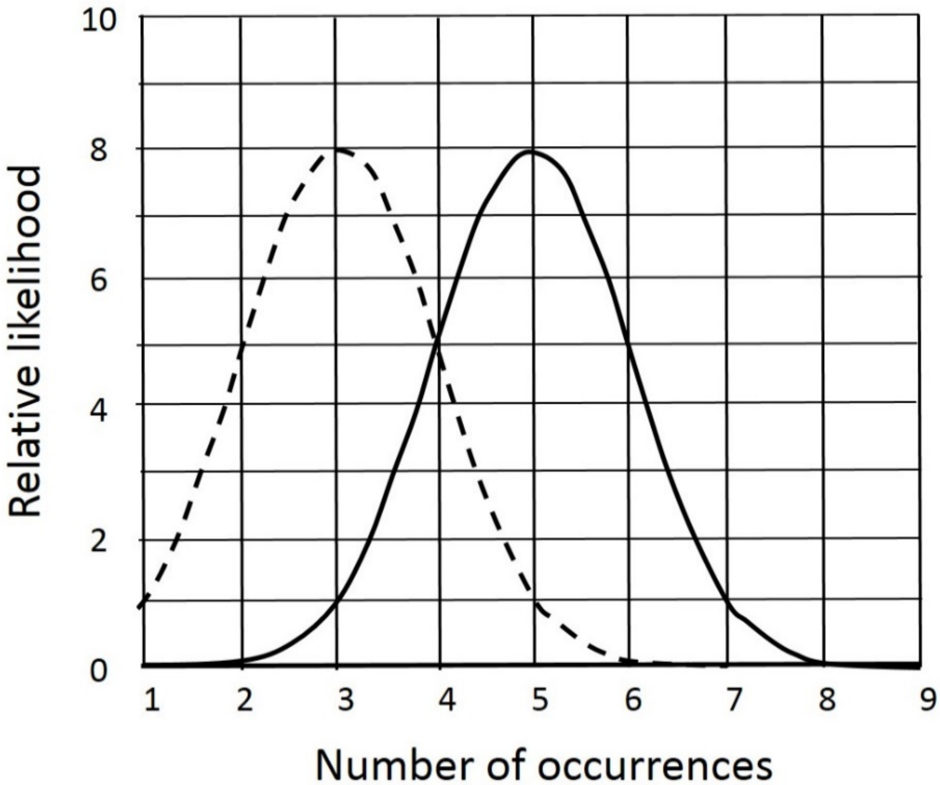

Figure 58. Normal distribution showing the number of times (3 to 7) an event with an annual exceedence probability of 0.050 occurs in 100 years (full line) and their likelihoods; for example, 5 events are 8 times as likely as 3 or 7 events. If the annual exceedence probability is reduced to 0.030 the number of occurrences (1 to 5) and their likelihoods are shown by the dashed line. Thus, if the annual probability is 0.030 rather than 0.050, then 30% of the time there will be the same or more occurrences in 100 years – meaning no or negative impact reduction.

With even rarer (and even more intense) events, whose annual probabilities are even lower, the situation is worse still. Say we reduce the annual probability of an event from 0.005 to 0.003; then the likely number of occurrences in any given 100 years, which was originally 0 or 1, remains 0 or 1, and the reduction of risk has no effect whatsoever on actual impact.

DRR thus leads reliably to impact reduction, over a chosen time period, only for events that occur frequently during that time. These are necessarily smaller, less intense events than those that occur more rarely, and their impacts will therefore be less. As noted in Section 4 above, the term "disaster" should be restricted to rare events. There is thus an irony in that disaster risk reduction only leads to resilience (impact reduction) for events that cannot be classed as disasters.

8. Disaster Impact Reduction

Since DRR does not reliably reduce the impacts of disasters, we are forced to look elsewhere for a basis for increasing resilience to disasters. The obvious place to look is towards directly reducing the impacts of future severe events, without considering their risk or probability (Disaster Impact Reduction, DIR). If this can be achieved, and adaptations developed so that the impacts of future events are reduced, then increased resilience is achieved. (So, incidentally, is reduced risk). Therefore, knowledge of the nature and magnitude of the community impacts that will result from the occurrence of severe hazard events during the next 100 years or so needs to be established.

Recalling that there is no way to reliably predict what type of hazard the next event will be, the event severity, or when the event will happen, this seems to be a tall order. Certainly, for a specified location, hazard science can constrain the type of event that can occur; it can also constrain the maximum credible severity of the event (bearing in mind, however, that several major earthquakes during the last two decades have exceeded their scientifically-determined maximum credible magnitude; Davies, 2015). For some types of event, the occurrence can be forecast to give days (storms and floods), weeks or even months (volcanic eruptions) of warning, with varying degrees of reliability. However, no warning greater than a matter of seconds is presently feasible for earthquakes, and hence very little for the hazard cascades they can initiate (tsunami; landslide – damming – dambreak flooding - river aggradation – flooding; landslide-tsunami).

This difficulty, however, reduces considerably when it is appreciated that communities do not need to be resilient to earthquakes, or eruptions, or storms. According to the present definition, they need to be resilient to their impacts. This can be taken further; resilience does not take the form of coping with specific assets being damaged, it takes the form of being less impacted by the societal consequences of any asset damage. For example, a community does not need to be resilient to a particular bridge collapsing, it needs to be resilient to the loss of services (transport, power, communications) resulting from that collapse.

This situation is simplified even further when it is recalled that the particular disaster a community needs to be most resilient is the next one to affect it. Thus, the community as it is at present needs to be resilient only to the impacts of the next disaster.

The situations that affect a community as a consequence of any disaster fall into a small number of categories, such as:

- deaths and injuries,
- loss of supplies (food, fuel, goods),
- loss of communications,
- loss of power,
- loss of water services (fresh water, storm water, waste water),
- loss of social services (finance, care, medical),
- loss of business,
- loss of societal structures and functions.

Thus, if a community can adapt so that it is better able to maintain its existence in the face of these losses, it becomes more resilient to future disasters of any type. This is equivalent to what Helm (2015) calls "intrinsic resilience". If these losses can be reduced by pre-event adaptations, the community is better able to continue to function through and beyond the disaster. Some adaptation strategies to this end are now obvious, such as stockpiling of emergency food, fuel and medical supplies, satellite phones and stand-by generators. Reducing vulnerability to loss of power, water supplies and/or transport is more difficult, involving perhaps installation of a backup water, or power and fuel supply, or constructing alternative road access – here redundancy implies improved resilience, but at a considerable cost; this can, however, be spread over considerable time, because although the next disaster can in principle occur at any time, there may be several years or decades before it does occur. Again, as noted in 3.3 above, the immediacy of investment in disaster resilience is for the community to decide.

The preceding discussion has deliberately been framed in general terms, in order to preserve clarity of the fundamental concepts of resilience, however, we recognise that this clarity is to some extent artificial, in that it glosses over the many social and political factors that in reality contribute to the vulnerability and resilience of communities. For example, a community may be vulnerable to disaster impact because dwellings are sited close to a river, but the obvious strategy of relocation may be unworkable for numerous reasons. The riverside location may be a major source of revenue for the town, for example through tourism (e.g. Espiner & Becken, 2014). Moreover, Tierney (2006) explores the contribution of social inequality to disaster impacts; the community may not have adequate resources or alternative sites for the dwellings, nor the political influence to remedy these needs.. Social inequality may be able to be offset, however, by recognition of and utilisation of the community's social capital – its resources of connectedness, linkages memory and networks (e.g. Aldrich and Meyer, 2015).

9. Increasing community resilience: the scenario approach

While Section 8 emphasises that increasing community resilience has much more to do with the impacts that hazard events have on community services than with specific hazard events themselves, a clear idea of the types of threat that the community faces from hazard events is nevertheless a useful starting point for improvement of community resilience. This is because the decisions that are made about community adaptability to hazard impacts depend critically on the way of life and aspirations of the community, and thus must be made by the community itself (Section 5.3).

To make these decisions, the community needs to understand

1. the "hazard-scape" (the range of types and magnitudes of hazards that can affect the community; derived by hazards scientists in consultation with the community), and
2. the "asset damage-scape" (similarly, the types and intensities of asset damages that can occur; derived by engineers in consultation with the community), so that these drivers can be integrated with
3. the "community-scape" (the ways in which the community functions as a social, cultural and commercial entity; known intuitively by the community), to derive
4. the full "impacts-scape" (as outlined in Section 8) – to which resilience is required by way of adaptation.

A potential way of making relevant information available to the community is by way of three sets of scenarios:

1. Hazard event scenarios,
2. Asset damage scenarios, and
3. Community impact scenarios.

Hazard event scenarios represent the range of hazard events that the community can experience, limited by its geological and geomorphic setting. The chosen event intensities need to be at the upper end of what is likely (Section 7), but the exact choice of hazard and intensity needs to be made by the community in discussion with hazard scientists and officials, because the community has a clear picture of its desired future and what it is willing to pay for disaster resilience (Section 5.3).

Damage scenarios are developed from the hazard event scenarios, by the community in discussion with hazard scientists, engineers and officials; through these discussions the community becomes aware of the full range of likely direct hazard event effects. In this phase it is important to consider regional infrastructure damage too, because this may seriously impact the functioning of the community even if direct community impacts are moderate, or even zero.

The community impact scenarios are developed by the community (who possess expert local knowledge in this topic) in discussion with local authorities and infrastructure providers, for example to estimate how long it will take to improve and restore regional critical infrastructure levels of service (Zorn et al., 2018).

These scenarios will also be influenced by increasing knowledge of hazard events in other places – for example, the 2016 Mw7.8 Kaikōura earthquake in New Zealand did not involve rupture of a single major fault, but involved rupture of about 20 minor faults, many previously unknown (Hamling et al., 2017). Hence major earthquakes are not limited to major faults, as has previously been assumed worldwide, implying that major earthquakes might occur almost anywhere that there are many minor faults. The Kaikōura earthquake also informed impact assessments and expected recovery trajectories for infrastructure stakeholders, particularly following damages to road and rail networks. These are already being used by infrastructure stakeholders including the national road and rail operators and Civil Defence Emergency Management within New Zealand to plan for other hazards elsewhere in the country (Chapter 3).

It is important to realise that here, the scenarios facilitate collaboration with, as opposed to top-down education of, the community. For example, while the scientists and engineers are expected to provide greater levels of technical knowledge, the community may also be able to provide local knowledge which may alter the scientific and engineering knowledge. No group knows everything, and each will learn from others through the scenarios. This is possible because accurate communication of scenario information is much easier than accurate communication of technical scientific information (such as probabilistic risk) and technical engineering information. The scenario information is about hazard events, asset damage, and the impacts of asset damage on community life – which all parties are familiar with by experience, even if at much lower severities, or by knowing about impacts on other communities. All of these can be conveyed comprehensibly in everyday terms, and indeed the community can contribute substantially to their development. Not only can scenario information be more easily understood by all involved, but this also means that no-one is in a position of privileged knowledge, and thus of power, by virtue of profession or position. Everyone involved in scenario discussions has all the relevant information available to them and equally comprehensible by them. This is extremely important in enabling trust among the participants, which is itself a pre-requisite for open communication.

Once the full set of scenarios has been developed, and community members have an understanding of the nature, intensity and duration of the service losses they can expect to suffer under these scenarios, development of adaptation strategies can begin.

10. Selection of impacts scenario

In the present context, an impact scenario describes only one of the many possible sets of impacts that can affect the community as a result of the next disaster. Any chosen scenario is very likely to differ from the set of impacts that will in fact occur, but, given that the full range of impacts of all these sets (although able to be envisioned) is probably too broad to serve as a sensible target for adaptation, a specific set needs to be chosen for consideration. For example, a chosen scenario may assume that specific buildings and sections of infrastructure are damaged. In the next disaster, these exact buildings and sections of infrastructure are unlikely to all be impacted, or to be the only ones impacted. However, all buildings within the community may have been strengthened as a result of the scenario, so those that are impacted in the event are damaged less. The more severe is the chosen scenario, the greater the confidence the community can have that its chosen adaptations will allow it to survive and prosper through and beyond the event; but, as noted above (Section 5.3), more serious adaptations to disaster scenarios will incur greater costs and therefore leave less resource to devote to resilience to lesser threats. Hence, again, the choice of scenario must be made by the community according to its own degree of risk acceptance or aversion and its own vision of the future. Nevertheless, even if an event occurs that exceeds the chosen scenario, the adaptations to lesser scenarios will reduce impacts to some degree. So, the choice of scenario is not simple, but is important.

The choice of scenario is also important because a common criticism of the scenario approach, particularly the use of hazard event scenarios, is that it only deals with one of the many situations that may occur in the future and ignores all others – so it is a random shot in the dark with no certainty of usefully representing the next event. By contrast, the risk approach deals with the full range of known events and integrates their effects into the risk distribution, and an optimised solution can be derived by probabilistically optimising the countermeasures. Besides the intrinsic unreliability of the risk approach outlined above (Section 7), this objection mostly focusses only on impacts scenarios, whose possible range is qualitatively much smaller than that of the events scenarios. The remaining objections, which relate to the apparently random selection of an impacts scenario as a basis for planning, disappear when, as a result of considering the full range of likely impacts scenarios up to and including a maximum credible impacts scenario, the community chooses the scenario(s) it wants to use for planning. In fact, careful selection of an impacts scenario as the basis for resilience planning is potentially far more reliable than any probabilistically-derived "optimal" decision. In addition, adaptation to the wrong event still has benefits when a different event occurs, because adaptation is to impacts, not events (Section 8).

An excellent example of the benefits of pre-adaptation to the wrong scenario is given by the experience of an electricity utility in the 2010-2011 Christchurch earthquake sequence. Following the publication of knowledge about the magnitude and probability of a rupture on the plate-boundary Alpine Fault, and its likely effects on Christchurch although about 150 km away (Lamb, 1997), Orion carried out strengthening of their electricity supply infrastructure in anticipation of this event. The next event to affect the system, however, was the series of local earthquakes that devastated Christchurch starting in 2010; thanks to its upgrading in anticipation of the different event, the Orion network required less reinstatement work following these events than would otherwise have been the case (Massie and Watson, 2011).

Finally, it is important to recognise that the above processes of scenario development and choice, and planning, take place in an environment in which power structures and politics can play a major role. Particularly at the local level these factors have the potential to see vested interests override community welfare. Such influences are intrinsically difficult to counter, and indeed to discern, given the wide range of backgrounds and personalities present in any group grappling with community adaptation planning. In spite of these complications, however, there is accumulating evidence that scenario-based community resilience planning can lead to better decisions than traditional top-down governance (Chapter 4).

11. Use of the term "risk"

The present work is based on UNISDR (2017) definitions, particularly of "disaster risk", and the emphasis in that definition that risk is determined probabilistically. On that basis, it has been made clear that "risk management" cannot reliably result in increased resilience, and the present proposals may thus appear to be a substantial departure from current standard practice. However, in reality, many uses of the term "risk" in both technical and policy literature do not conform to the UNISDR definition. Many uses of "risk" in fact mean "impact", and indeed only make sense in that context. It is enlightening, when reading reports and attending seminars and other addresses, to mentally alter every use of "risk" to "impact"; very often the sense of meaning is clarified, while often the meaning does not change, and rarely is it distorted.

Thus, the present suggestions, while clarifying some potential strategies for approaching resilience, are less revolutionary than might appear at first sight. It is likely that professional risk managers will object to the side-lining of probabilistic risk suggested herein, and scientists dedicated to increasing the sophistication of event magnitude-frequency distributions in the pursuit of resilience may resist these suggestions. In response, it is emphasised that probabilistic risk reduction has its place in dealing with events that happen frequently in a realistic time-frame; further, these events are often sufficiently well-described that accurate probability distributions can be derived – which is certainly not the case for less frequent events. But they are not disasters.

Probabilistic risk is most reliable where very large numbers of events are involved; for example, in insurance and reinsurance. Here, the organisation involved is dealing with the full range of events of all types that occur over very wide areas of the planet, and the summed impacts of even major disaster events can be reliably predicted on a statistical basis for time periods as short as a year (most insurance premiums are adjusted annually). The same may apply, to some extent, to a national government developing policy for spatially-averaged "resilience" for a whole country; the drawback in this context is that individual communities will not be reliably served by this policy, so from the community perspective, the policy will be perceived to fail from time to time (Davies, 2015). A democratically-elected government is vulnerable at the polls to such perceptions.

Finally, the present work is by no means merely a semantic argument. In discussions and planning for reducing disaster impacts, lack of clarity about the meanings of "risk" and "resilience" can at the very best result in considerable time being wasted, and at the worst in unreliable strategies being adopted at great cost that fail to reduce the impacts of the next disaster to befall a community. The internal inconsistencies that have been demonstrated in high-level official definitions foster this lack of clarity, and the confusion that results inhibits the development and implementation of effective measures to reduce disaster impacts.

12. Conclusions

1. UNISDR is the leading organisation globally coordinating, campaigning and advocating for disaster reduction; its by-line is "Connect and convince to reduce disaster impacts" (https://www.unisdr.org/). The organisation's terminology (UNISDR, 2017) unequivocally implies that resilience to disasters can be achieved by risk reduction. However, this implication is false. It is only valid for events that occur frequently in the time-frame of interest to an affected community, and such events cannot be "disasters", according to the terminology (Section 4). Instead, Disaster Risk Reduction is reliable when applied to ensembles of many events, when the occurrence of events is more likely to closely match their probabilities. Insurance and reinsurance are examples of such contexts.
2. Disaster impacts are the effects on society of the damage caused to community and regional assets by hazard events. These include deaths and injuries, loss of supplies (food, fuel, goods), loss of communications, loss of power, loss of water services (fresh water, storm water, waste water), loss of social services (finance, care, medical), loss of business and loss of societal structures and functions. Impacts are largely independent of the hazard type (Section 8).
3. Reduction of disaster impacts is equivalent to increasing disaster resilience; this cannot, however, be reliably achieved by Disaster Risk Reduction. By contrast, measures specifically designed to reduce the impacts of disasters lead reliably to increased resilience (Section 8).
4. Disaster Impact Reduction can be approached by community-based development of hazard, asset-damage and community-impact scenario sets, also involving officials and experts. The scenario approach critically facilitates collaboration, as opposed to top-down education of the community. This means the impact scenarios can form the basis for planning to reduce community impacts by adaptation measures (Section 9).
5. Scenarios and adaptation strategies can be selected by community-official-expert collaborations, based on the community's knowledge of its capabilities and its aspirations (Sections 5.3 and 9). While important, the criticality of scenario selection is moderated by the fact that adaptation to the wrong event will nevertheless result in reduced impacts, because of the general nature of the impacts (Section 8).

13. Acknowledgements

This work was funded by New Zealand National Science Challenge "Resilience to Nature's Challenges". We gratefully acknowledge ongoing discussions on the topics herein with Thomas Wilson and Sarah Beaven.

14. References

Aitsi-Selmi, A., Egawa, S., Sasaki, H., Wannous, C. and Murray, V., 2015. The Sendai framework for disaster risk reduction: Renewing the global commitment to people's resilience, health, and well-being. International Journal of Disaster Risk Science, 6(2), pp.164-176.

Aldrich, D.P. and Meyer, M.A., 2015. Social capital and community resilience. American Behavioral Scientist, 59(2), pp.254-269.

Chatenoux, B. and Peduzzi, P., 2007. Impacts from the 2004 Indian Ocean Tsunami: analysing the potential protecting role of environmental features. Natural Hazards, 40(2), pp.289-304.

Criss, R.E. and Shock, E.L., 2001. Flood enhancement through flood control. Geology, 29(10), pp.875-878.

Davies, T., 2015. Developing resilience to naturally triggered disasters. Environment Systems and Decisions, 35(2), pp.237-251.

Department for International Development (DFID) 2011. Defining disaster resilience: a DFID approach paper. London: Department for International Development, p. 20.

Emergency Management Australia (EMA) 1998. Australian emergency management glossary. (Australian emergency manual). Emergency Management Australia (EMA), Canberra, Australia

Espiner, S & Becken, S 2014. Tourist towns on the edge: Conceptualising vulnerability and resilience in a protected area tourism system. Journal of Sustainable Tourism, 22 (4), pp. 646-665.

Gilbert, S.W., 2016. Disaster resilience: A guide to the literature. NIST Special Publication 1117, Office of Applied Economics Building and Fire Research Laboratory Gaithersburg, Maryland 20899 CreateSpace Independent Publishing Platform, 113p.

Hamling, I. J., Hreinsdóttir, S., Clark, K., Elliott, J., Liang, C., Fielding, E., Litchfield, N., Villamor, P., Wallace, L., Wright, T. J., D'Anastasio, E., Bannister, S., Burbidge, D., Denys, P., Gentle, P., Howarth, J., Mueller, C., Palmer, N., Pearson, C., Power, W., Barnes, P., Barrell, D. J. A., Van Dissen, R., Langridge, R., Little, T., Nicol, A., Pettinga, J., Rowland, J., and Stirling, M., 2017. Complex multifault rupture during the 2016 Mw 7.8 Kaikōura earthquake, New Zealand. Science, 356(6334), p.eaam7194.

Helm, P., 2015. Risk and resilience: strategies for security. Civil Engineering and Environmental Systems, 32(1-2), pp.100-118.

Intergovernmental Panel on Climate Change (IPCC), 2012: Glossary of terms. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups

I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 555-564.

International Standards Organisation (ISO), I., 2009. 31000: 2009 Risk Management—Principles and Guidelines. International Organization for Standardization, Geneva, Switzerland.

Kelman, I. (ed.). 2017. Disaster Definitions. Version 3, 13 April 2017 (Version 1 was 12 July 2004). Downloaded from http://www.ilankelman.org/miscellany/DisasterDefinitions.doc.

Lamb, J., 1997. Risks & Realities: A Multi-disciplinary Approach to the Vulnerability of Lifelines to Natural Hazards. Centre for Advanced Engineering, University of Canterbury, New Zealand, 312p.

International Standards Organisation (ISO), I., 2009. 31000: 2009 Risk Management—Principles and Guidelines. International Organization for Standardization, Geneva, Switzerland.

Manyena, S.B., 2006. The concept of resilience revisited. Disasters, 30(4), pp.434-450.

Massie, A. and Watson, N.R., 2011. Impact of the Christchurch earthquakes on the electrical power system infrastructure. Bulletin of the New Zealand Society for Earthquake Engineering, 44(4), pp.425-430.

Mileti, D.S. and Gailus, J.L., 2005. Sustainable development and hazards mitigation in the United States: Disasters by design revisited. Mitigation and adaptation strategies for global change, 10(3), pp.491-504.

Mochizuki, J., 2014. Decision-making, policy choices and community rebuilding after the Tohoku disaster. IDRiM Journal, 4(2), pp.103-118.

Paton, D. and Johnston, D., 2017. Disaster resilience: an integrated approach. Charles C Thomas Publisher.

Pearce, L, 2003. Disaster Management and Community Planning, and Public Participation: How to Achieve Sustainable Hazard Mitigation. Natural Hazards, 28, pp. 211-228.

Pelling, M., 2012. Resilience and transformation. Climate change and the crisis of capitalism. A chance to reclaim self, society and nature. Oxford: Routledge, pp.51-65.

ReliefWeb. 2008. ReliefWeb Glossary of Humanitarian Terms. ReliefWeb, Geneva, Switzerland.

Shuckburgh, E., Mitchell, D. and Stott, P., 2017. Hurricanes Harvey, Irma and Maria: how natural were these 'natural disasters'? Weather, 72(11), pp.353-354.

Suppasri, A., Shuto, N., Imamura, F., Koshimura, S., Mas, E. and Yalciner, A.C., 2013. Lessons learned from the 2011 Great East Japan tsunami: Performance of tsunami countermeasures, coastal buildings, and tsunami evacuation in Japan. Pure and Applied Geophysics, 170(6-8), pp.993-1018.

Tierney, K., 2006. Social inequality, hazards, and disasters. In: On risk and disaster: Lessons from Hurricane Katrina, (ED. Daniels, R.J., Kettl, D.F. and Kunreuther, H.) University of Pennsylvania Press, pp.109-128.

Twigg, J., 2004. Disaster risk reduction: mitigation and preparedness in development and emergency programming. Overseas Development Institute (ODI).

Ulanowicz, R., Goerner S., Lietar B. and Gomez R., 2009. Quantifying sustainability: resilience, efficiency, and the return of information theory. Ecological Complexity 6:27–36

United Nations Department of Humanitarian Affairs (UN DHA). 1992. Internationally Agreed Glossary of Basic Terms Related to Disaster Management. UN DHA, Geneva, December 1992.

United Nations International Strategy for Disaster Reduction (UNISDR) (2005) Hyogo Framework for Action 2005-2015: Building the resilience of nations and communities to disasters (HFA). World Conference on Disaster Reduction 18-22 January 2005, Kobe, Hyogo, Japan.

United Nations International Strategy for Disaster Reduction (UNISDR) 2017. Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction. 41p, December 2016

Zorn, C., Davies, A.J., Robinson, T.R., Pant, R., Wotherspoon, L. and Thacker, S., 2018. Infrastructure failure propagations and recovery strategies from an Alpine Fault earthquake scenario. 16th European Conference on Earthquake Engineering, Thessaloniki, Greece.

Appendix C. Timeline of key events during the first 100 days following the “Kaikoura” earthquake

Key	
	Hazardous Event
	Road
	Rail
	Air
	Shipping

Table 13. “Kaikōura” earthquake timeline: key transport events.

Date	Event Day	Day	Time	Event	Source
DAY 1: Monday 14th November 2016					
14/11/2016	1	Mon	00:02	M_w 7.8 earthquake.	Canterbury CDEM
14/11/2016	1	Mon	02:34	Wairau River Bridge to Waipara (SH1) closed.	Marlborough CDEM, NZ Transport Agency
14/11/2016	1	Mon		Waipara to Springs Junction (SH7) closed.	NZ Transport Agency
14/11/2016	1	Mon		Culverden to Kaikōura (Route 70) closed under Civil Defence Emergency Management act.	Canterbury CDEM, NZ Transport Agency
14/11/2016	1	Mon		The Main North Line between Picton and Christchurch is closed.	KiwiRail
14/11/2016	1	Mon		All ferry sailings cancelled until Wellington and Picton ferry terminals are inspected and cleared to re-open.	KiwiRail
14/11/2016	1	Mon		The rail-enabled Aratere Interislander ferry not shipping, pending clearance of the Wellington rail span.	KiwiRail

14/11/2016	1	Mon	06:00	Picton to Blenheim (SH1) only open for Class 1 vehicles, up to 50kg. Heavier vehicles backed up for several kilometres along the highway.	Marlborough CDEM
14/11/2016	1	Mon	10:15	Diversion around Wairau River Bridge in place on SH1, via SH62 and SH6.	NZ Transport Agency
14/11/2016	1	Mon	13:00	Lyttleton and Timaru ports reopen.	Canterbury CDEM
14/11/2016	1	Mon	14:00	Engineers on site at Wairau River Bridge, which remains closed.	Marlborough CDEM
14/11/2016	1	Mon	15:22	Waipara to Cheviot (SH1) open.	NZ Transport Agency
14/11/2016	1	Mon	15:25	Blenheim to Seddon (SH1) open.	NZ Transport Agency
14/11/2016	1	Mon	15:30	SH7A open to light vehicles, will close again at 8pm.	NZ Transport Agency
14/11/2016	1	Mon	15:59	Waipara to Springs Junction (SH7) open.	NZ Transport Agency
14/11/2016	1	Mon	16:00	Kaikōura airfield functional and operating. Priority is to get tourists out of Kaikōura.	Canterbury CDEM
14/11/2016	1	Mon	17:00	Supplies have started arriving in Kaikōura by helicopter.	Canterbury CDEM
14/11/2016	1	Mon	20:00	SH7A closed for repairs.	NZ Transport Agency
14/11/2016	1	Mon	20:00	The Wairau River Bridge is expected to reopen this evening. Emergency vehicles only are cleared on SH1 south of Seddon. Fuel is being supplied to Seddon residents.	Marlborough CDEM
14/11/2016	1	Mon		Wellington Port ferries operating, many cargo ships are diverting to ports including Napier, Tauranga and Auckland.	CentrePort
DAY 2: Tuesday 15th November 2016					
15/11/2016	2	Tue	06:00	Work begins to clear SH1 to Kaikōura from the south.	Canterbury CDEM

15/11/2016	2	Tue	07:54	SH7A open to light vehicles. No towing. There is a stop/go sign at the Waiau River bridge.	NZ Transport Agency
15/11/2016	2	Tue	08:30	SH6 is closed from north of Rai Valley township to 7 km south of Havelock: Rai Valley township has been isolated by flooding on one side and a slip on the other. SH63 remains open but has surface flooding.	Marlborough CDEM
15/11/2016	2	Tue	09:45	Route 70 being investigated as alternate route to access Kaikōura.	Canterbury CDEM
15/11/2016	2	Tue		Air New Zealand is operating scheduled flights from Marlborough.	Marlborough CDEM
15/11/2016	2	Tue		Air New Zealand is operating an additional return service between Wellington and Marlborough today to increase capacity.	Marlborough CDEM
15/11/2016	2	Tue		SoundsAir fly four (10-person) flights from Kaikōura to Christchurch.	The Marlborough Express
15/11/2016	2	Tue		Pelorus Air are providing a charter service between Marlborough and Kaikōura.	Marlborough CDEM
15/11/2016	2	Tue		Two out of three Interislander ferries (the Kaiarahi and Kaitaki) begin carrying freight and vehicle passengers only. Foot traffic passengers are suspended due to terminal damage.	KiwiRail
15/11/2016	2	Tue		KiwiRail has set up coordination centres in Christchurch and Wellington to enable a closer working relationship with NZ Transport Agency as work continues to assess the damage to the Main North Line and SH1.	KiwiRail
15/11/2016	2	Tue	16:45	Rai Valley to Renwick (SH6) open.	NZ Transport Agency
15/11/2016	2	Tue	23:59	198 people evacuated from Kaikōura via NZDF helicopters.	Canterbury CDEM

"First few days"				Army convoys travel through to Kaikōura. Critical infrastructure vehicles allowed through later.	Canterbury CDEM
DAY 3: Wednesday 16th November 2016					
16/11/2016	3	Wed	06:00	HMNZS Wellington and Canterbury arrive at Kaikōura.	Canterbury CDEM
16/11/2016	3	Wed	10:48	SH7A Open (no restrictions), will close at 8pm for repairs. Expected to be reopened by 7am.	NZ Transport Agency
16/11/2016	3	Wed		Culverden to Waiau (Route 70) reopens.	NZ Transport Agency
16/11/2016	3	Wed		Mangamaunu to Peketa (SH1, via Kaikōura) reopens.	NZ Transport Agency
16/11/2016	3	Wed		Picton to Ward (SH1) open.	NZ Transport Agency
16/11/2016	3	Wed		Photo ID required to travel South of Seddon on SH1 while the emergency operation is underway.	Marlborough CDEM
16/11/2016	3	Wed		Intercity Coach resumes Nelson to Picton service, begins Christchurch to Picton service via SH7, SH65, SH6 and SH63.	Marlborough CDEM
16/11/2016	3	Wed		All freight lines in the North Island and south of Christchurch are open and operating.	KiwiRail
16/11/2016	3	Wed		Freight is being delivered to the container transfer site at Blenheim and then by truck to Christchurch, either via SH63, SH6, SH65 and SH7 or the West Coast region.	KiwiRail
16/11/2016	3	Wed		Burnham Wharf (Wellington) reopened for shipping services.	CentrePort
16/11/2016	3	Wed	12:00	Leader Road closed	NZ Transport Agency
16/11/2016	3	Wed	14:30	HMNZS Canterbury loading ~380 people for evacuation to Christchurch.	Canterbury CDEM
16/11/2016	3	Wed		SoundsAir flies four flights from Kaikōura to Wellington (10-person flights).	The Marlborough Express

16/11/2016	3	Wed	23:09	SH63, SH6, SH65 and SH7 is recommended SH1 detour.	NZ Transport Agency
16/11/2016	3	Wed	23:59	165 people evacuated from Kaikōura via NZDF helicopters.	Canterbury CDEM
DAY 4: Thursday 17th November 2016					
17/11/2016	4	Thurs		SH7A Open	NZ Transport Agency
17/11/2016	4	Thurs	01:00	HMNZS Canterbury arrived at Lyttleton. Evacuated 449 people from Kaikōura.	Canterbury CDEM
17/11/2016	4	Thurs	08:00	Temporary Restricted Area established around Kaikōura to facilitate safe aircraft operations. Expires 22/11/16 17:00.	Canterbury CDEM
17/11/2016	4	Thurs	10:16	Controlled access for residents and emergency services between Cheviot and Goose Bay (SH1)	NZ Transport Agency
17/11/2016	4	Thurs	12:10	SH1 now open fully between Picton and just south of Ward. Speed restrictions and many one lane sections along route. A checkpoint is installed at the end of this stretch, where the road remains closed.	Marlborough CDEM, NZ Transport Agency
17/11/2016	4	Thurs	16:30	Bluebridge resume foot passenger travel, Interislander cannot take foot passengers from Picton to Wellington, but can take foot passengers from Wellington to Picton.	Marlborough CDEM
DAY 5: Friday 18th November 2016					
18/11/2016	5	Fri		HMNZS Te Kaha, HMNZS Endeavour, USS Sampson, HMAS Darwin and HMCS Vancouver call at Wellington harbour, before leaving for Kaikōura.	CentrePort
18/11/2016	5	Fri	06:00	HMNZS Canterbury and international fleet arrives at Kaikōura, with supplies including 1000+ portable toilets.	Canterbury CDEM
18/11/2016	5	Fri		Wellington Port reopens for cruise ships following inspections.	CentrePort

18/11/2016	5	Fri		Freight demand on New Zealand's busiest domestic sea route, Auckland to Christchurch, has doubled following the massive Kaikōura Earthquake on Monday.	KiwiRail
18/11/16	5	Fri		Two out of three Interislander ferries (the Kaiarahi and Kaitaki) begin carrying foot traffic passengers from Picton to Wellington.	KiwiRail
DAY 6: Saturday 19th November 2016					
19/11/2016	6	Sat	18:00	HMNZS Canterbury departs Kaikōura for Lyttleton. Remainder of fleet depart for Wellington.	Canterbury CDEM
DAY 7: Sunday 20th November 2016					
20/11/2016	7	Sun	18:00	HMNZS Canterbury arrived at Lyttonton. Evacuated 186 people.	Canterbury CDEM
WEEK 2: Monday 21st to Sunday 27th November 2016					
21/11/2016	8	Mon	18:00	HMNZS Canterbury stood down.	Canterbury CDEM
20/11/2016	8	Mon	18:00	SoundsAir launches temporary services, flying daily between Kaikōura and Christchurch and Blenheim (10-person flights). On the first flights SoundsAir deliver two tonnes of mail for New Zealand Post (Christchurch to Kaikōura), and will make deliveries until the road has reopened.	Canterbury CDEM, Marlborough CDEM
22/11/2016	9	Tue		A limited container service begins from Wellington Port following implementation of on-ship cranes and mobile cranes on the wharf. The port's container cranes are currently non-operational and there is liquefaction and substantial differentiated settlement across the container operations area.	CentrePort
22/11/2016	9	Tue	18:13	M5.7 earthquake near Scargill.	Canterbury CDEM
25/11/2016	12	Fri	15:00	First Route 70 convoy of 81 vehicles from Kaikōura to Waiau (planned).	Canterbury CDEM

25/11/2016	12	Fri		Wellington Port receives HMNZS Otago to resupply following earthquake recovery work in Kaikōura.	CentrePort
26/11/2016	13	Sat		Stock trucks pass through Route 70 on animal welfare grounds. Does some damage to the road.	Canterbury CDEM
WEEKS 3+: Monday 28th November to Friday 9th December 2016					
28/11/2016	15	Mon		KiwiRail enters the Coastal Shipping market with a new NZ Connect service, from Auckland's Wiri Inland Port and KiwiRail's Southdown Freight Hub to Lyttleton's Midland Port or KiwiRail's Christchurch terminal via ANL shipping services, in a partnership between KiwiRail, Ports of Auckland, Lyttleton Port and ANL Shipping.	KiwiRail
28/11/2016	15	Mon	19:00	Civil Aviation Authority restricted airspace over Kaikōura expires.	Canterbury CDEM
29/11/2016	16	Tue		KiwiRail's rail-enabled Interislander ferry, Aratere, resumes sailing for freight customers and foot passengers after the link span at Wellington's ferry terminal, used to load and discharge vehicles, was repaired. Rail link-span still under repair so no rail wagons able to be loaded into Aratere.	KiwiRail
29/11/2016	16	Tue	07:00	NZ Transport Agency now managing and operating Route 70. Process in place from managing public access to Route 70.	Canterbury CDEM
4/12/2016	21	Sun	12:00	M 5.5 earthquake near Seddon.	Canterbury CDEM
6/12/2016	22	Mon		SoundsAir adds additional flights between Christchurch and Blenheim for the Christmas and New Year period.	Press
6/12/2016	23	Tue		The Wellington rail link-span is repaired, allowing rail wagons to be loaded on to the rail-enabled Aratere Interislander ferry, and so resume full service.	KiwiRail

6/12/2016	23	Tue		Waiau to Kaikōura controlled access (Route 70).	NZ Transport Agency
6/12/2016	23	Tue		Controlled access for residents and emergency services from Ward to Clarence (SH1).	NZ Transport Agency
12/12/2016	29	Mon	18:00	Picton to Clarence (SH1) reopens.	NZ Transport Agency
17/12/2016	34	Sat	16:00	NZ Transport Agency advises delays along advised SH1 detour (SH63, SH6, SH65, SH7) due to multiple roadwork sites.	NZ Transport Agency
21/12/2016	38	Wed		Waiau to Kaikōura open (Route 70).	NZ Transport Agency
21/12/2016	38	Wed	14:26	Cheviot to Goose Bay (SH1) open.	NZ Transport Agency
21/12/2016	38	Wed	14:26	Goose Bay to Peketa (SH1, via Kaikōura) open 6am - 8pm (SH1).	NZ Transport Agency
21/12/2016	38	Wed		Government announces the North Canterbury Transport Infrastructure Rebuild (NCTIR) alliance, between NZ Transport Agency, KiwiRail, Fulton Hogan, Downer, Higgins and HEB Construction, led by Duncan Gibb, former lead of the Stronger Christchurch Infrastructure Rebuild Team (SCIRT). NCTIR is responsible for managing and operating, as well as all recovery, rebuild and resilience works, on SH1 and Route 70.	Government
21/12/2016	38	Wed		Crane arrives to remove containers off train trapped outside Kaikōura, to be delivered by road.	Press
22/12/2016	39	Thurs		Christchurch to Picton route (SH7, SH65, SH6, SH63) speed limit reduced from 100 km/h to 80 km/h. Wairau River township speed limit reduced to 60 km/h.	Press

29/12/2016	46	Thurs	07:52	Hundalee to Kaikōura (SH1) closed due to weather conditions causing an increased risk of rockfall.	NZ Transport Agency
29/12/2016	46	Thurs	09:20	Hundalee to Kaikōura (SH1) reopened (6am - 8pm).	NZ Transport Agency
4/01/2017	52	Wed	14:20	Peketa to Goose Bay (SH1) closed due to weather conditions causing an increased risk of rockfall.	NZ Transport Agency
4/01/2017	52	Wed	17:00	Peketa to Goose Bay (SH1) reopened (6am - 8pm).	NZ Transport Agency
9/01/2017	57	Mon	05:35	Peketa to Hunalee (SH1) closed due to a slip.	NZ Transport Agency
9/01/2017	57	Mon	06:00	Stop/go required in various locations along SH7 for road pavement repairs. Expected to last until 20/1/17.	NZ Transport Agency
11/01/2017	59	Wed	09:52	Peketa to Hunalee (SH1) reopened (6am - 8pm).	NZ Transport Agency
16/01/2017	64	Mon		The first freight train to leave the Blenheim Freight Hub heading south successfully completes its journey to Lake Grassmere, opening the way for commercial goods to run again on this section of the South Island's Main North Line.	KiwiRail

Appendix D. Franz Josef participatory governance detailed timeline

Table 14. Franz Josef participatory governance detailed timeline.

Community Resilience Team			Working Group			Other events	
Date	**Workshop number**	**Issues**	**Date**	**Meeting number**	**Issues**	**Date**	**Issues**
						29-Feb-15	GNS presentation of Langridge & Ries (2009) and Langridge & Beban (2011)
						30- & 31-Feb-15	WDC Plan Change 7 hearing.
1-May-15	1	Expectation assessment, community knowledge on hazards/issues the community faces.					
						18-May-15	Plan Change 7 approved.
22- & 23-Jun-15	2 & 3	Group objectives, how to achieve objectives, short-term and long-term timelines. Decide to create summary document, to be first drafted by University of Canterbury.					
1-Jul-15		Summary document circulated.					
10-Jul-15		Summary document circulated to wider Franz Josef community email list, who are invited to be involved.	10-Jul-15		WDC Planning, Community and Environment Group Manager emails suggestion of Working Group to CDO		
						Jul-15	Two separate appeals lodged to the Environment Court against Plan Change 7.
			5-Aug-15	0	Open meeting convened by WDC and WCRC. Working Group formed.		
			12-Aug-15		Working Group membership established.		
13-Aug-15	4	Decide to address aims through participatory hazard mapping, emergency management scenario, and long-term sustainability scenario.					
			19-Aug-15	1	Establishing Terms of reference, developing priority projects list.		
						15- & 16-Aug-15	Plan Change 7 Environment Court hearing of the appeals.
24-Aug-15	5 & 6	Participatory hazard mapping workshops, including evening session to increase community input.					
			11-Sep-15	2			
						Sep-15	Formal mediation of Plan Change 7 between WDC and appeal parties.
			22-Sep-15		Draft Terms of Reference and Mission Statement circulated.		
			7-Oct-15	3			
						29-Oct-15	Appellants request Plan Change 7 is placed on hold. WDC complies.
						Oct-15	Environment Court grants a year's postponement of the implementation of Plan Change 7. Parties (WDC & appeals) must agree to a resolution or proceed to Environment Court.
27-Oct-15		University of Canterbury academics complete and circulate hazardscape.					
28-Oct-15	7	Participants review summary document and University of Canterbury hazardscape.					
						29-Oct-15	University of Canterbury academic presents hazardscape and background to Resilience Workshops to WDC.
			11-Nov-15	4	WCRC proposes hazardscape developed by GNS Science. Community rejects this proposal as unnecessary in the meeting. Outside of the meeting, council proceeds with this work following a Government grant.		
18-Dec-15		University of Canterbury academics send draft flood scenario to CDO, CDO replies with suggested edits.					
			20-Jan-16	5			
29-Jan-16	8	Flood scenario workshop.					
						24-Mar-16	Waiho river flood.
			30-Mar-16	6	Discussion of flood event. Resolved to start town planning shortly.		
13-Apr-16	9	Community Working Group reps begin town planning	13-Apr-16	7	Preliminary design workshop for town planning.		

Appendix D. Franz Josef participatory governance detailed timeline.

Community Resilience Team			Working Group			Other events	
Date	**Workshop number**	**Issues**	**Date**	**Meeting number**	**Issues**	**Date**	**Issues**
						13-May-16	Minister for the Environment (Nick Smith) and Maureen Pugh (National MP, Candidate for West Coast-Tasman and National MP) visit Franz Josef to understand natural hazard issues and outline the MfE is developing a national policy statement for natural hazards and will use Franz Josef as a case study to ensure this policy will work in practice.
			29-Jun-16	8			
						28-Jul-16	Waiho River Working Party formed to design and implement a long-term strategy for managing the Waiho River.
			25-Aug-16		Langridge et al. (2016) *Natural Hazard Assessment for the Township of Franz Josef, Westland District* GNS Hazardscape report published.		
			8-Sep-16	9	Discussion with MBIE, MfE, WCRC, WDC & NZTA following GNS Hazardscape report. "Next step" for MBIE/MfE: check GNS recommendations against Regional Growth Strategy, and develop business plan for relocation and river management (~10 year horizon). Working Group's focus has become medium-term (from short-term).		
						14-Nov-16	"Kaikōura" earthquake event.
			9-Dec-16	10	Tender for business plan, Regional Council (consulting with Waiho River Working Party) has drafted a long-term river management strategy. Locals raised Franz Josef resilience connections with "Kaikōura" earthquake.		
						15-Dec-16	Plan Change 7 appellants attend WDC meeting to agree resolution. Plan Change 7 removed by WDC.
			7-Mar-17	11	T&T tender confirmed as successful for 'Franz Josef Township: Natural Hazards Options Assessment and Cost Benefit Analysis'.		
			27-Mar-17		T&T draft case for change circulated to Working Group.		
			28- & 29-Mar-17		Open community meeting(s) with T&T.		
			29-Mar-17	12	T&T present plan for Options Assessment to working group. Options for river management are discussed.		
			19-Apr-17		Community meeting about options to repair/replace sewage ponds.		
			12-Jun-17	13	Open Options Assessment meeting. T&T outline 69 resilience options, but highlight a combined set of three options, to proceed into CBA.		
			26-Sep-17	14	T&T present Options Assessment findings, before report is finalised, including CBA. Open meeting held later in the day has the same function. Community consultation to proceed over the next two months, led by WCRC. T&T propose splitting Working Group into a new Governance Group/Future Franz structure.		
						20-Oct-17	T&T report published online.
28-Oct-17	10	Franz Josef CDEM Day, including earthquake scenario.					
						13- & 14-Dec-17	Drop-in sessions held with T&T to discuss options with community.
						2-Feb-18	Ex-cyclone Fehi event.
						20-Feb-18	Ex-cyclone Gita event.
12-Mar-18	11	Franz Josef/Lifelines long-term recovery earthquake scenario workshop.					
			22-Mar-18	15	Meeting to discuss Options Assessment outcomes and community elect representatives for Governance Group.		
			27-Mar-18	16	Governance Group, consisting of representatives from local and central government, Iwi, business and the Franz Josef community meet to begin the review of the Franz Josef community feedback survey.		
						3-Apr-18	Franz Josef Feedback Summary published.
			23-Apr-18	17	Governance Group/Future Franz structure and Terms of Reference are discussed, along with outcomes from the Options Assessment. Q&A with T&T over science concerns is to be facilitated by the regional council. The WDC is to tender for development of a business case to take to government, including full stakeholder engagement (beyond WCRC consultation).		

Appendix E. Franz Josef risk governance actor arrangement between 2016 and 2018

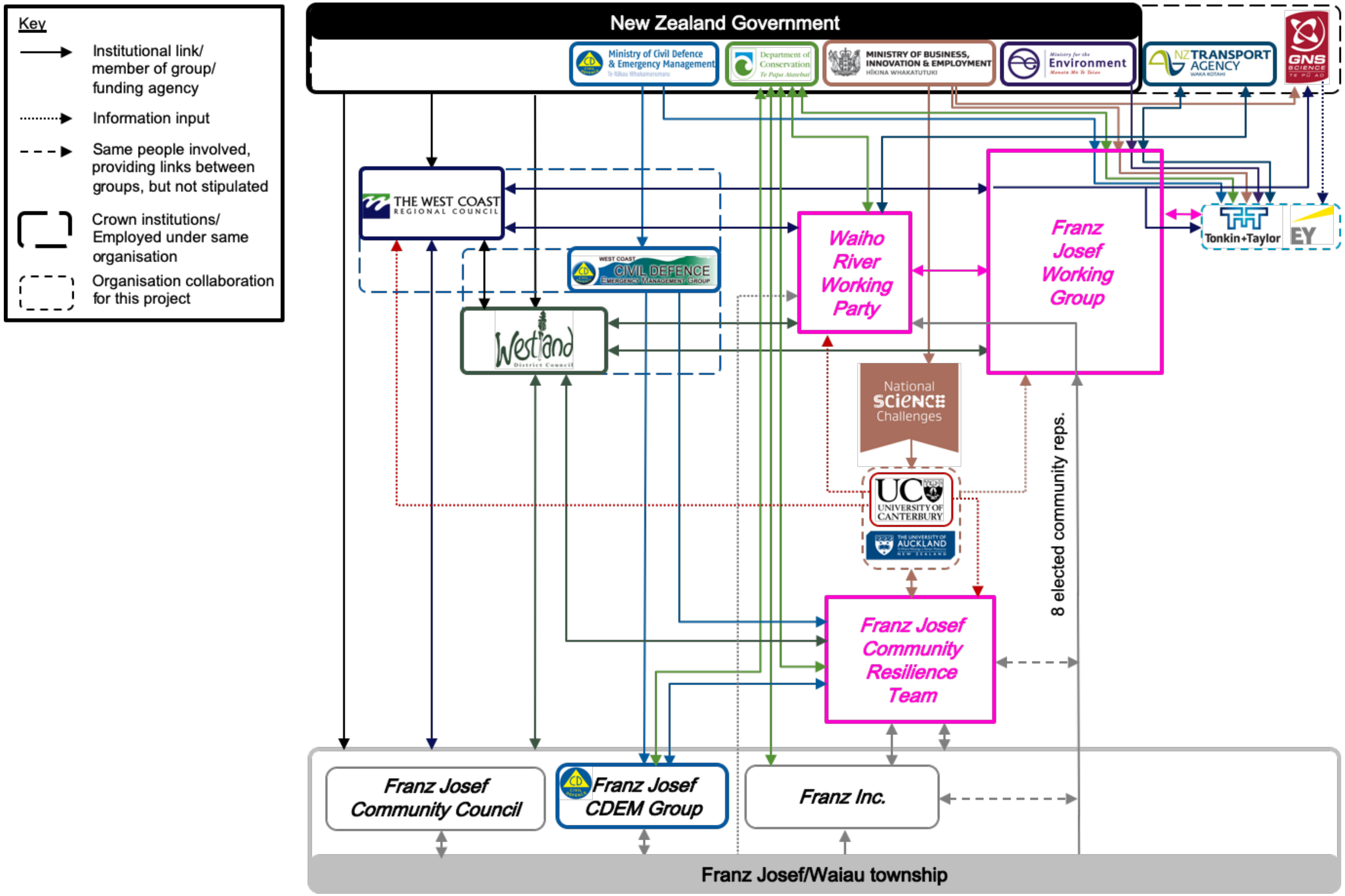

Figure 59. Franz Josef risk governance actor arrangement between 2016 and 2018.

Appendix F. The AF8+ advisory impact scenario maps

The AF8+ hazard scenario was partially presented in the form of hazard maps, included below. These were modified in a series of workshops to create AF8+ impact scenarios. A disclaimer was attached to each of these hazard maps, as follows:

Disclaimer

The AF8+ scenario, co-created and used to facilitate discussion and collaboration within the workshops, is designed to provide an example of an extreme earthquake for response and recovery planning in the South Island of New Zealand, with a focus on the West Coast and Franz Josef township. It is a realistic but extreme-case scenario, detailing earthquakes and their associated ground motions, landslides, and transposed real-world aftershock and rainfall sequences. The AF8+ scenario was compiled using the best scientific knowledge currently available (Orchiston et al., 2016). It is important to stress these maps detail expectations based on individual and collective understandings of the AF8+ hazard scenario, which was co-created into an impacts scenario within workshops. Recovery strategies and service levels were estimated in workshops for this AF8+ scenario only.

It is vital to understand that the AF8+ scenario is **NOT A PREDICTION** of what will happen during and after the next major earthquake that affects the West Coast (which may not be on the Alpine Fault). The underlying philosophy is that if we plan for an extreme case, we improve our ability to cope with less severe events (“expect the worst, hope for the best”).

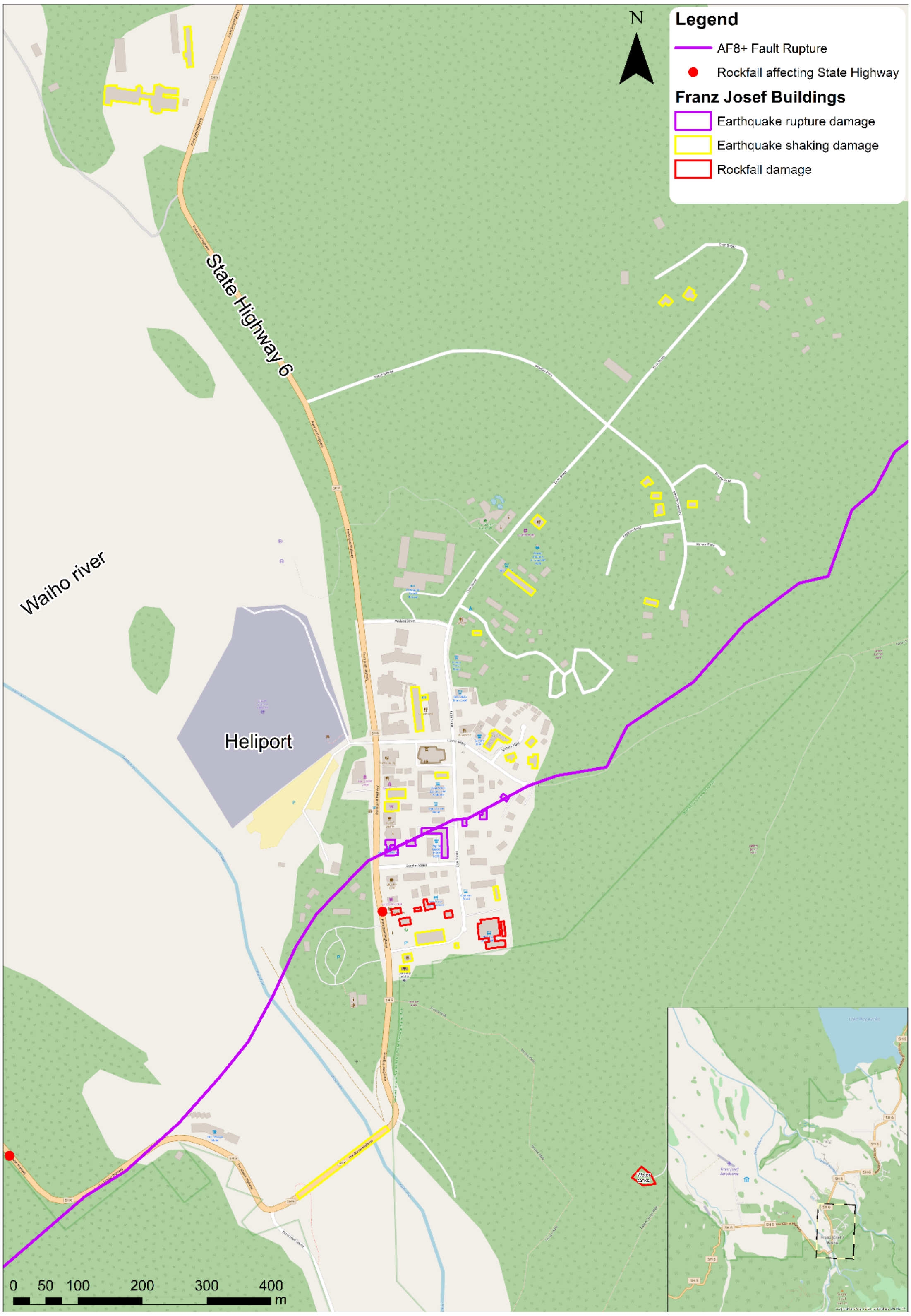

Figure 60. The AF8+ hazard map for Franz Josef township (T = 1 day).

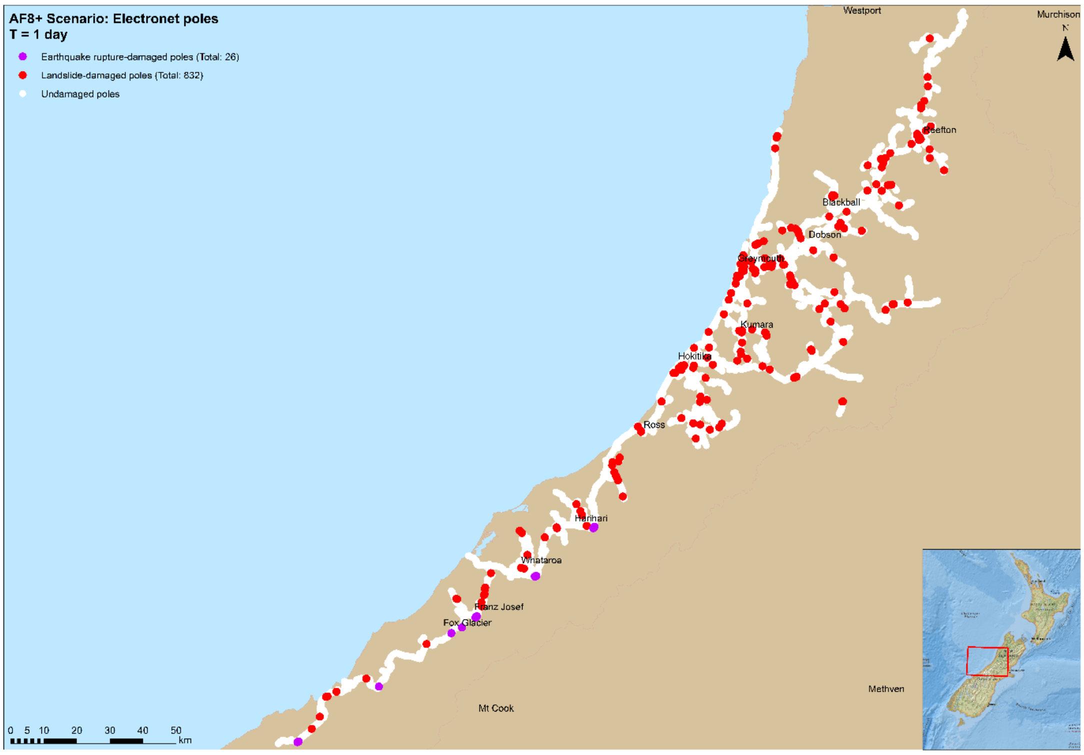

Figure 61. The AF8+ hazard map for Westpower electricity poles (T = 1 day).

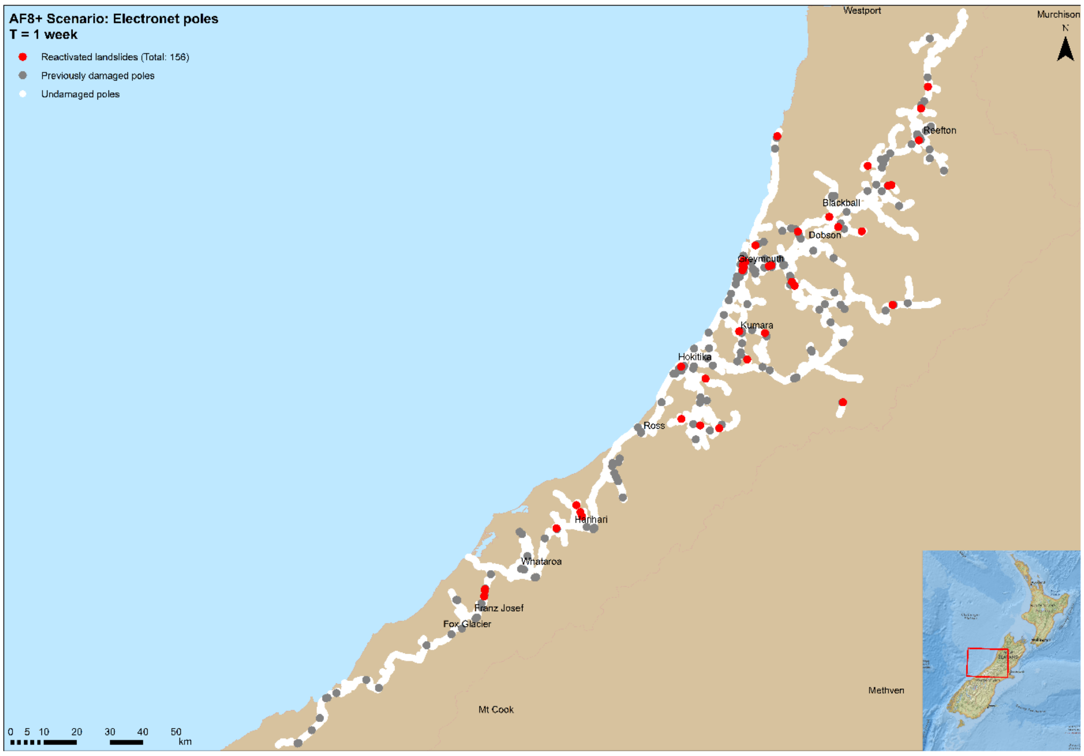

Figure 62. The AF8+ hazard map for Westpower electricity poles (T = 1 week).

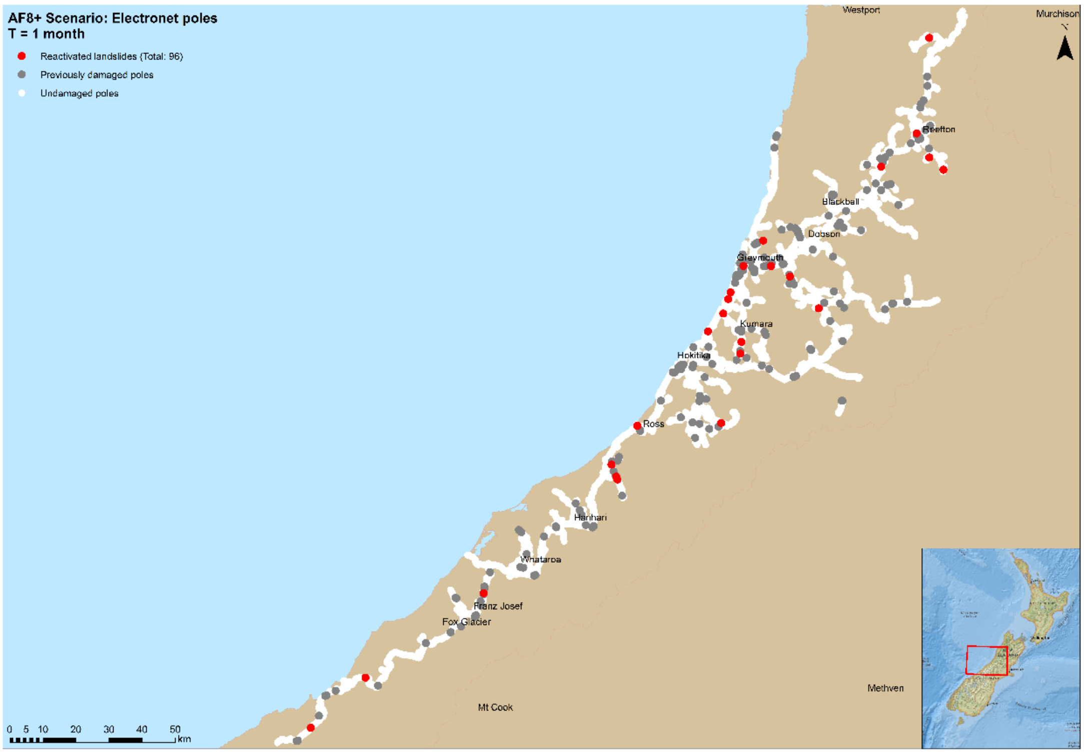

Figure 63. The AF8+ hazard map for Westpower electricity poles (T = 1 month).

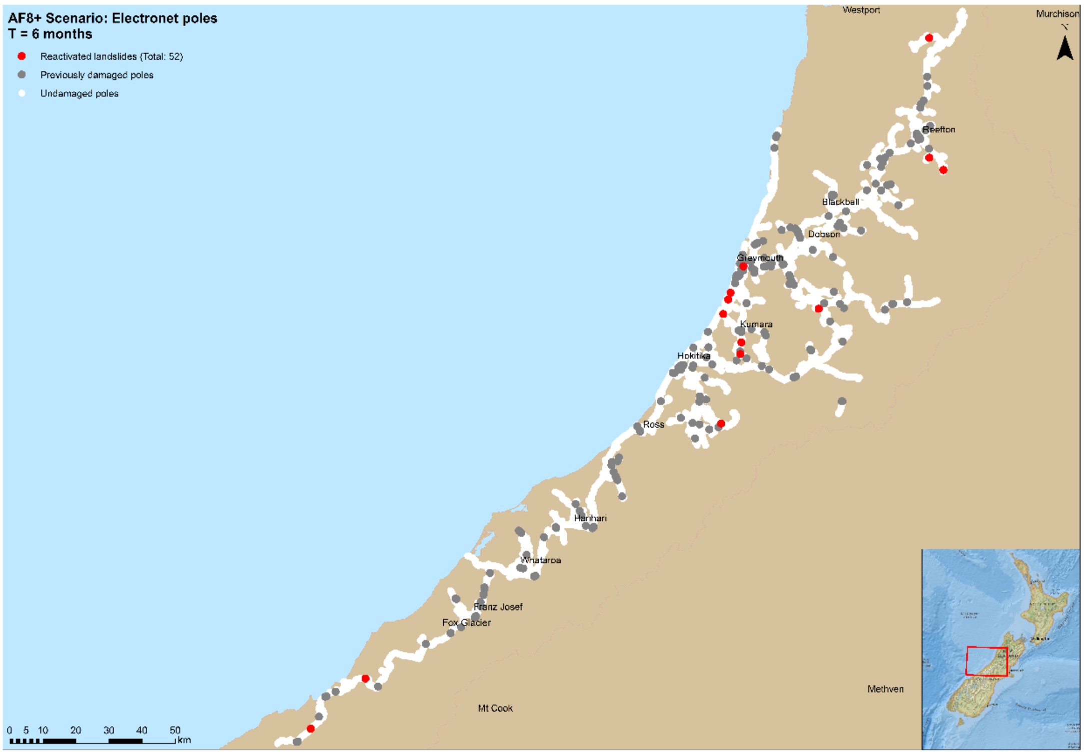

Figure 64. The AF8+ hazard map for Westpower electricity poles (T = 6 months).

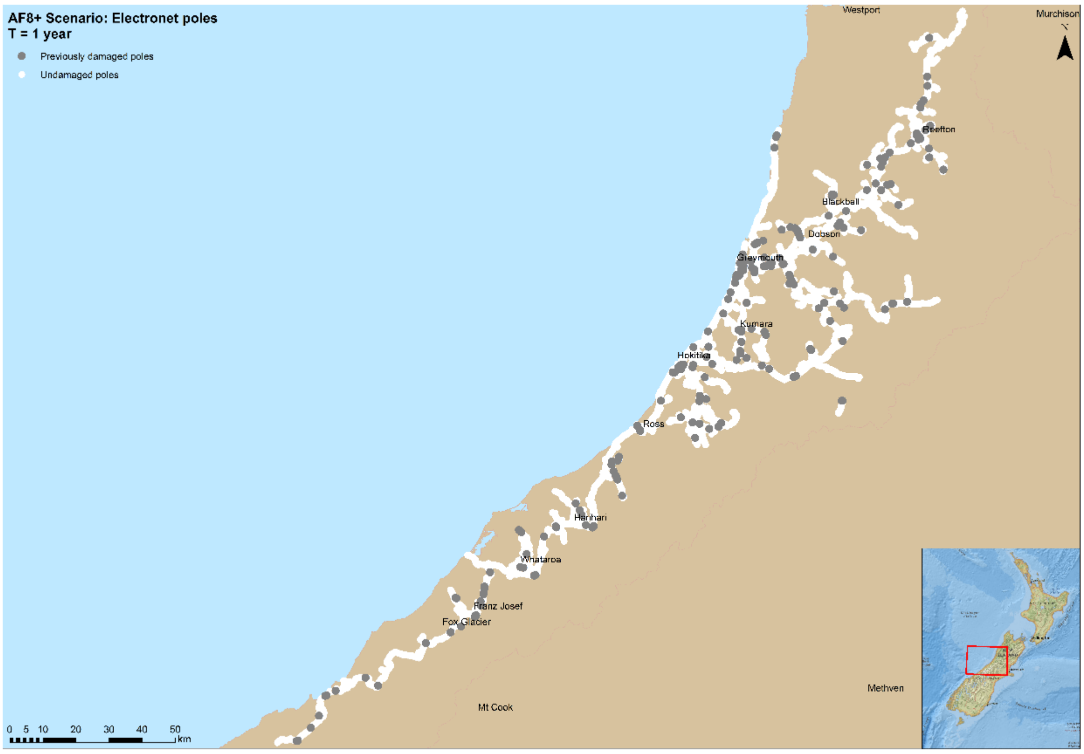

Figure 65. The AF8+ hazard map for Westpower electricity poles (T = 1 year).

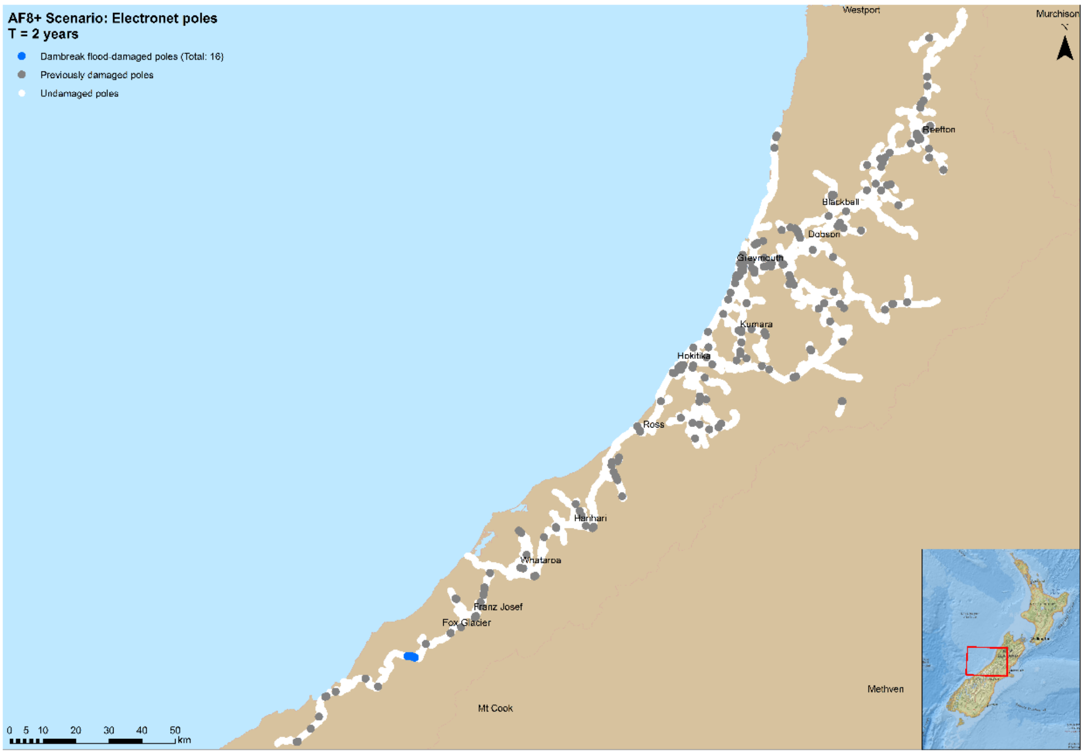

Figure 66. The AF8+ hazard map for Westpower electricity poles (T = 2 years).

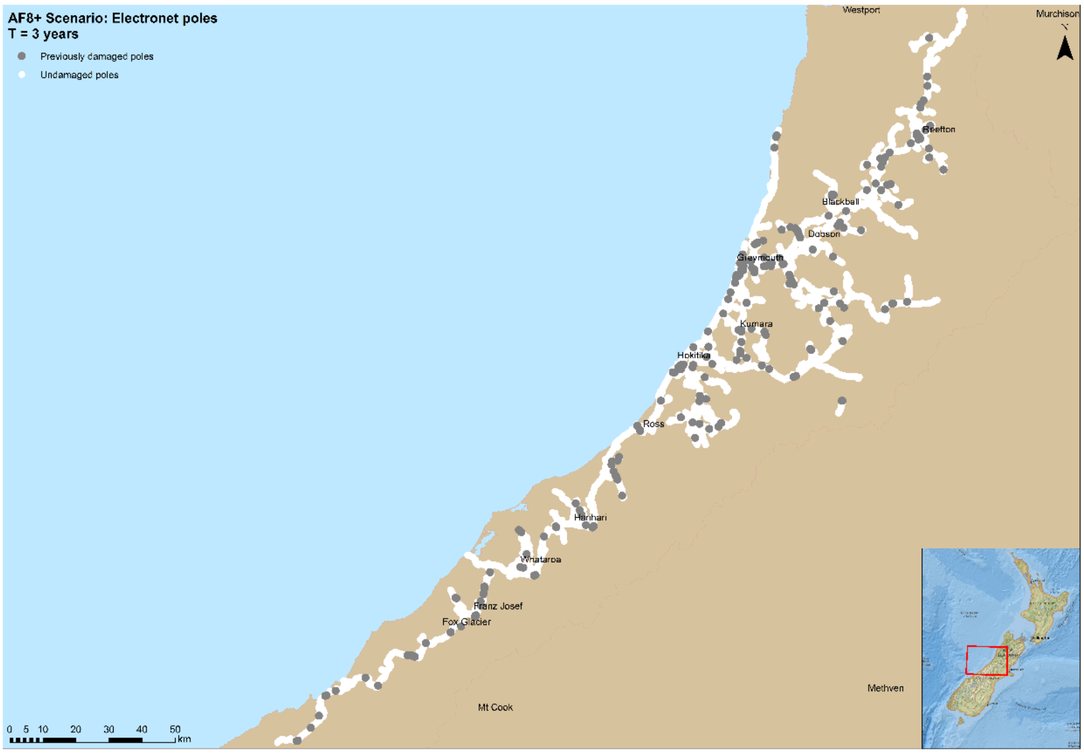

Figure 67. The AF8+ hazard map for Westpower electricity poles (T = 3 years).

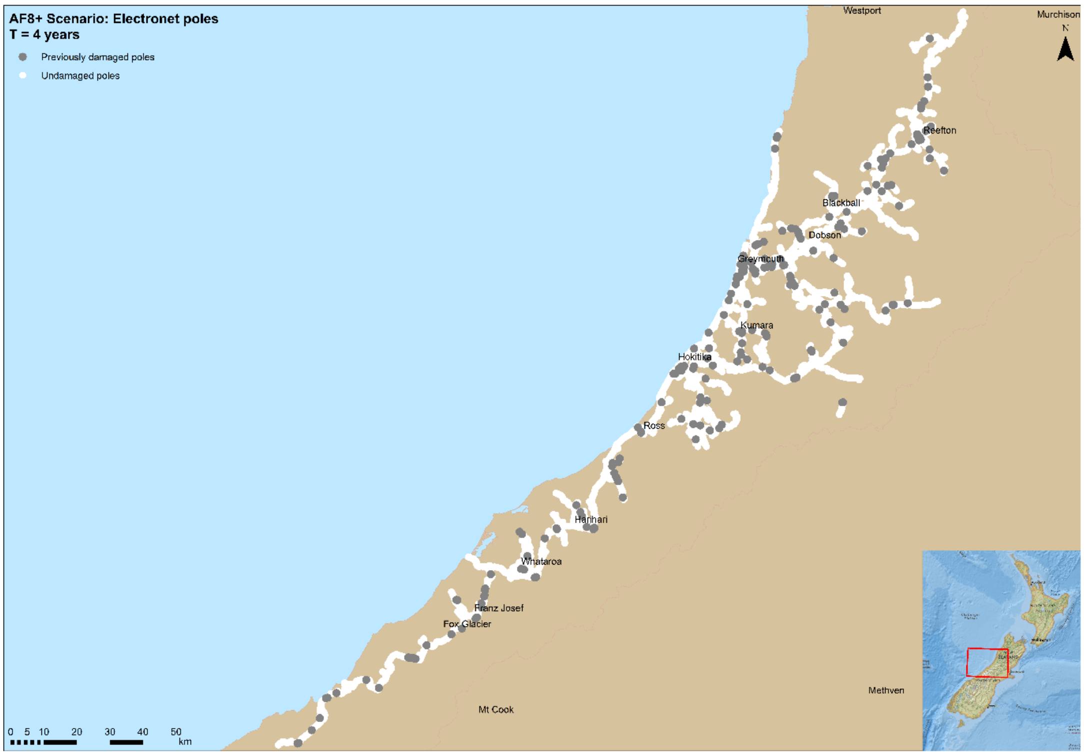

Figure 68. The AF8+ hazard map for Westpower electricity poles (T = 4 years).

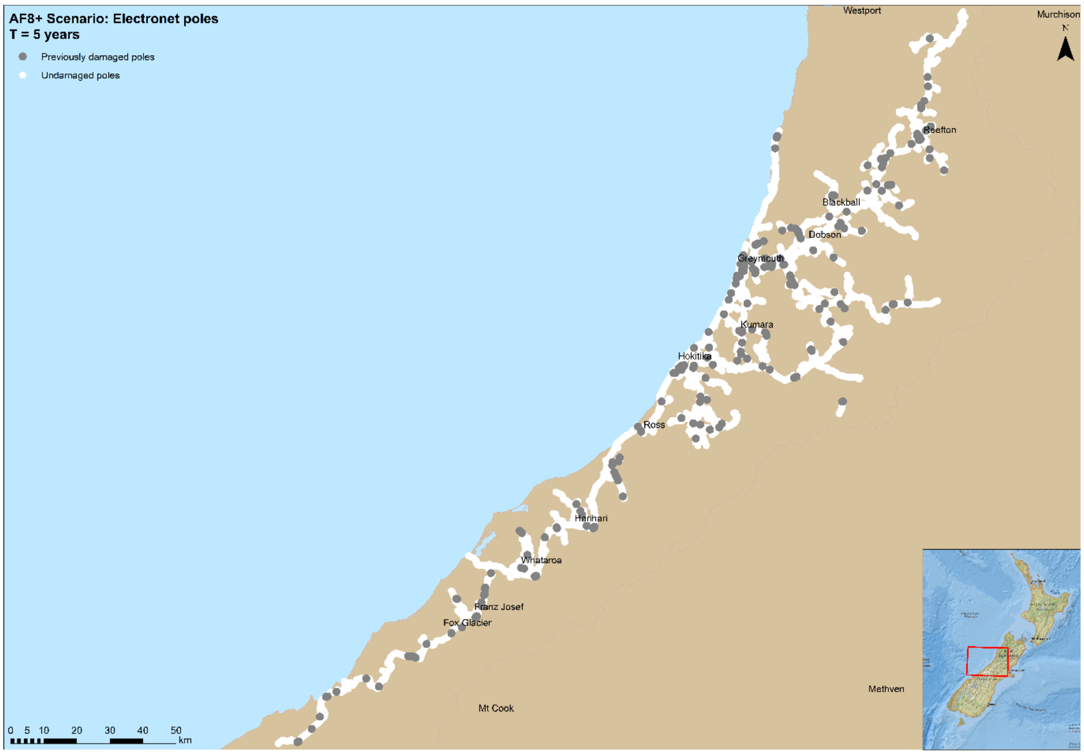

Figure 69. The AF8+ hazard map for Westpower electricity poles (T = 5 years).

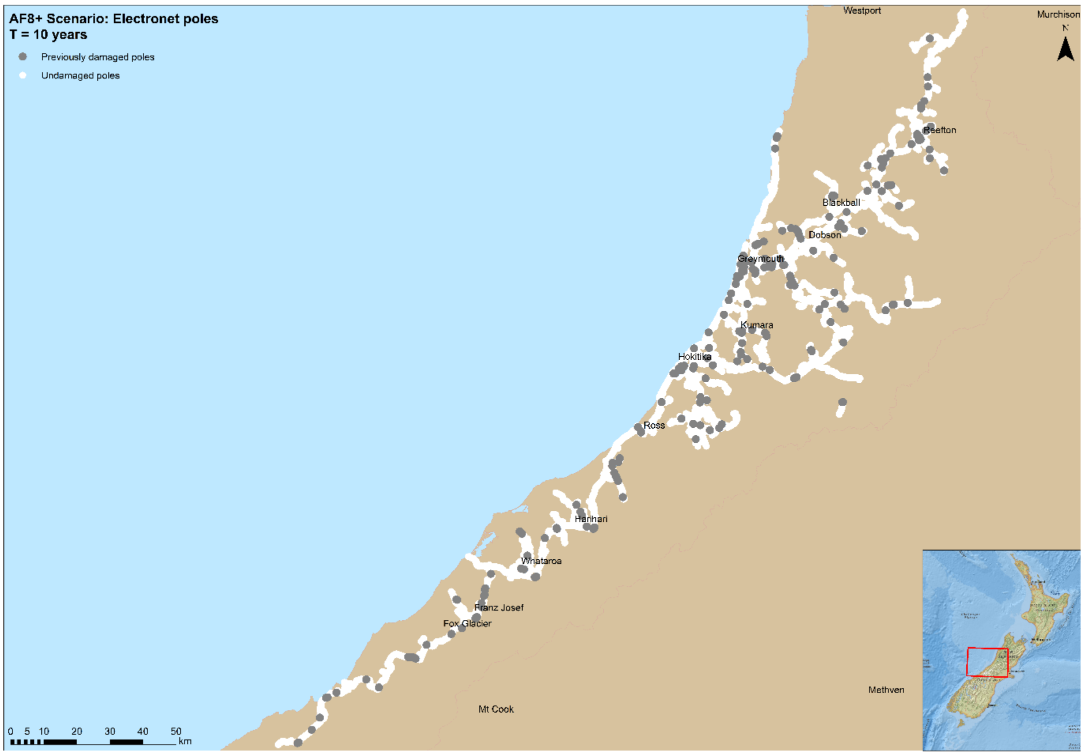

Figure 70. The AF8+ hazard map for Westpower electricity poles (T = 10 years).

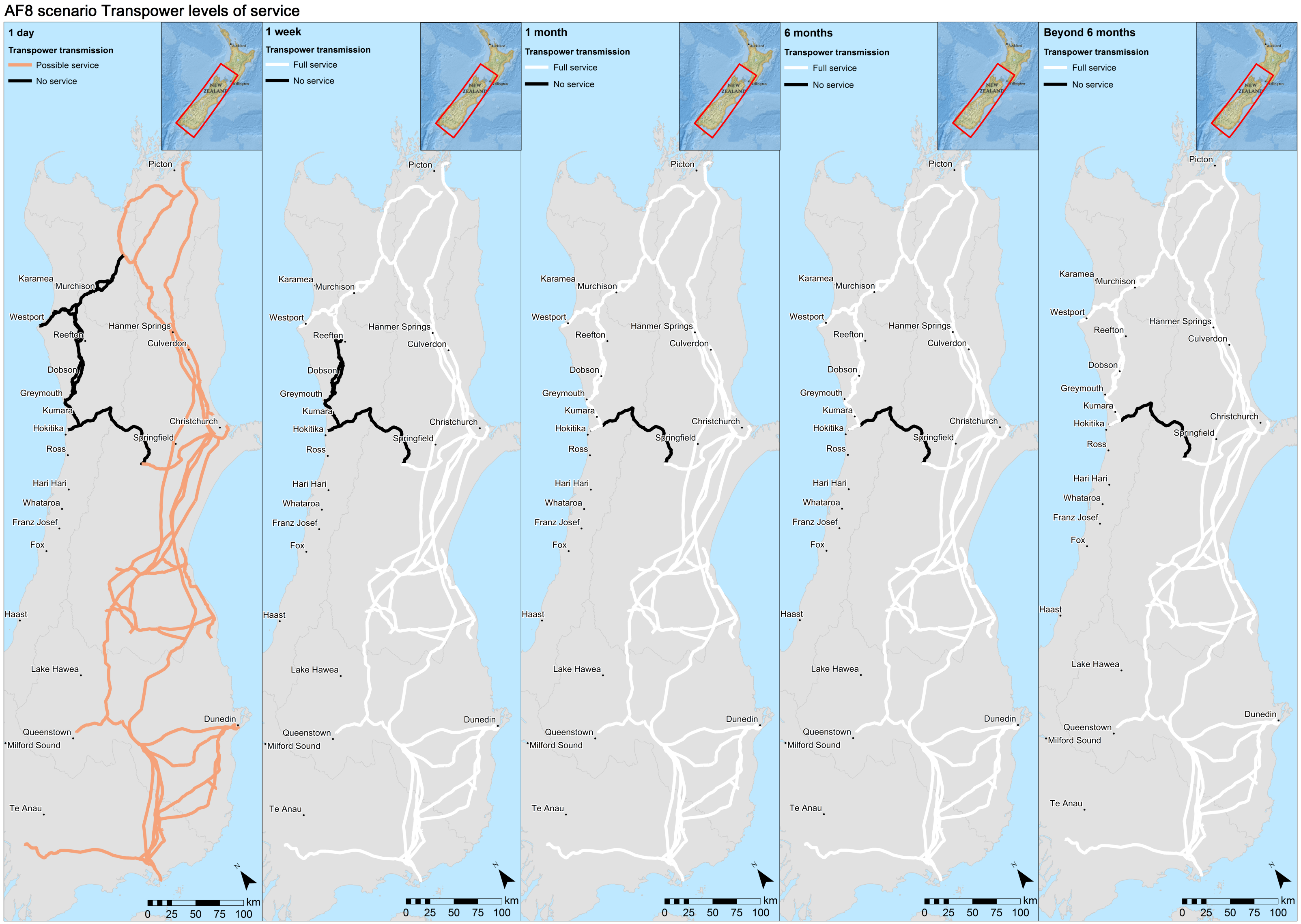

Figure 71. The AF8+ impact maps for South Island electricity transmission service levels.

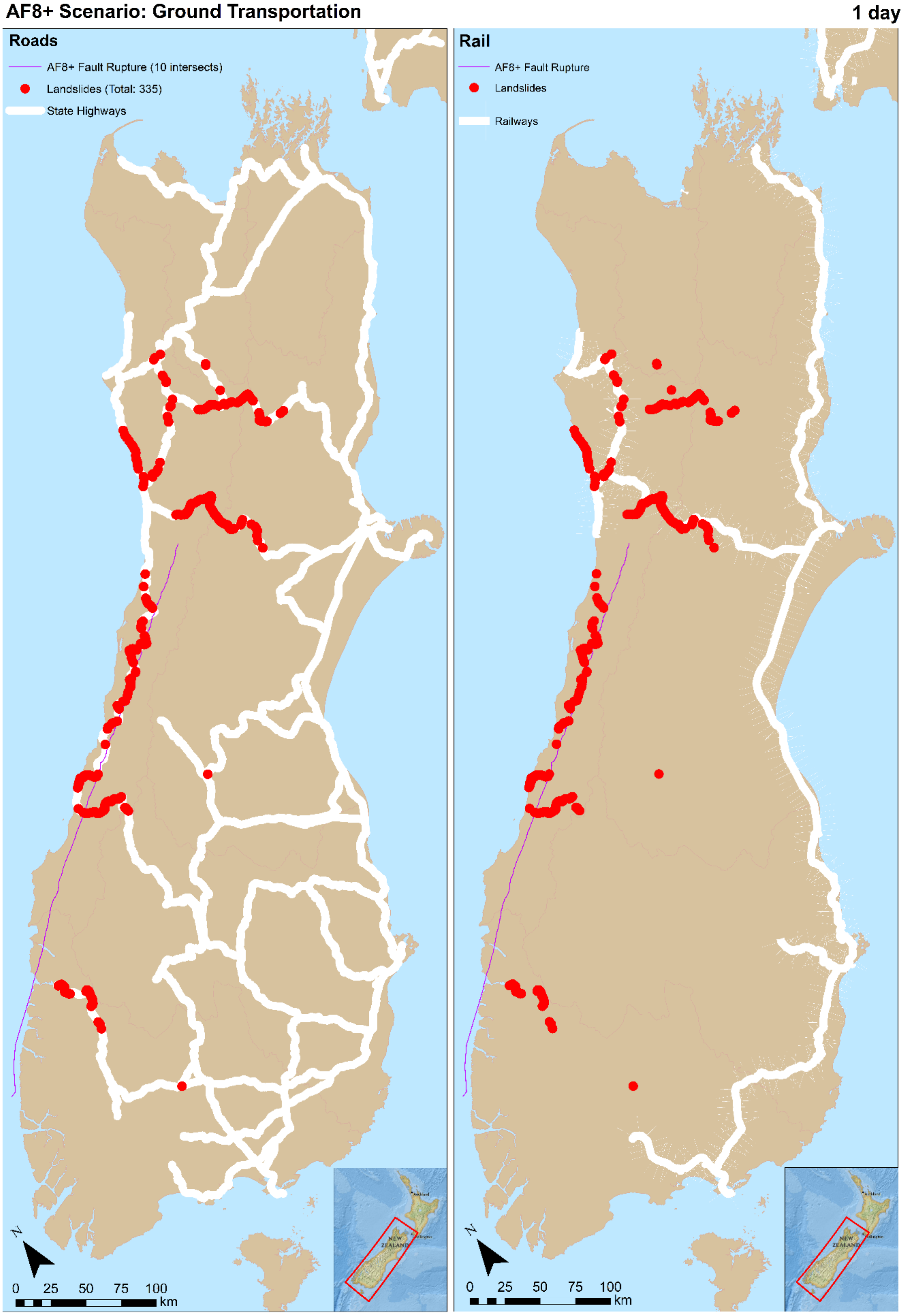

Figure 72. The AF8+ hazard map for State Highways and rail lines (T = 1 day).

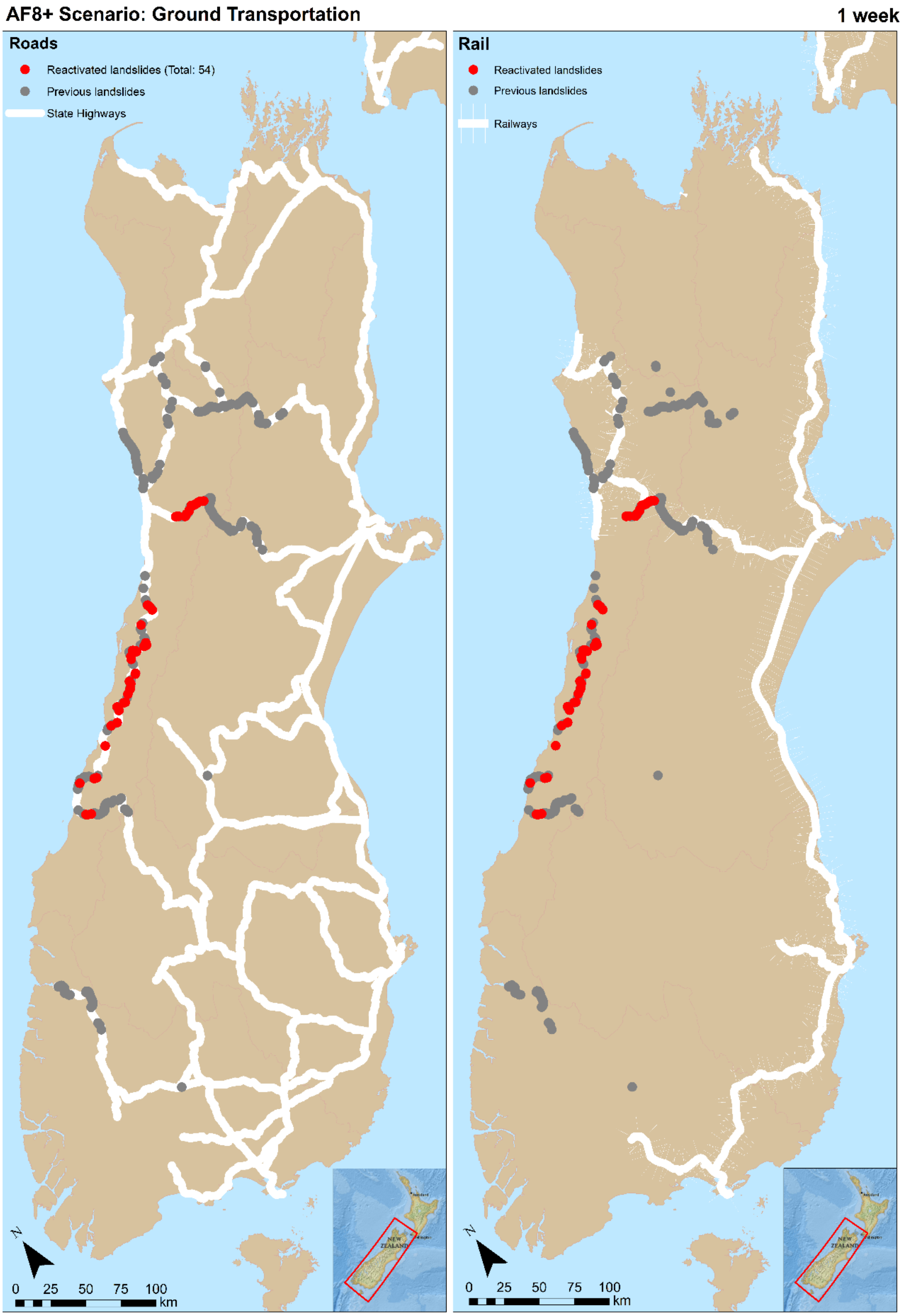

Figure 73. The AF8+ hazard map for State Highways and rail lines (T = 1 week).

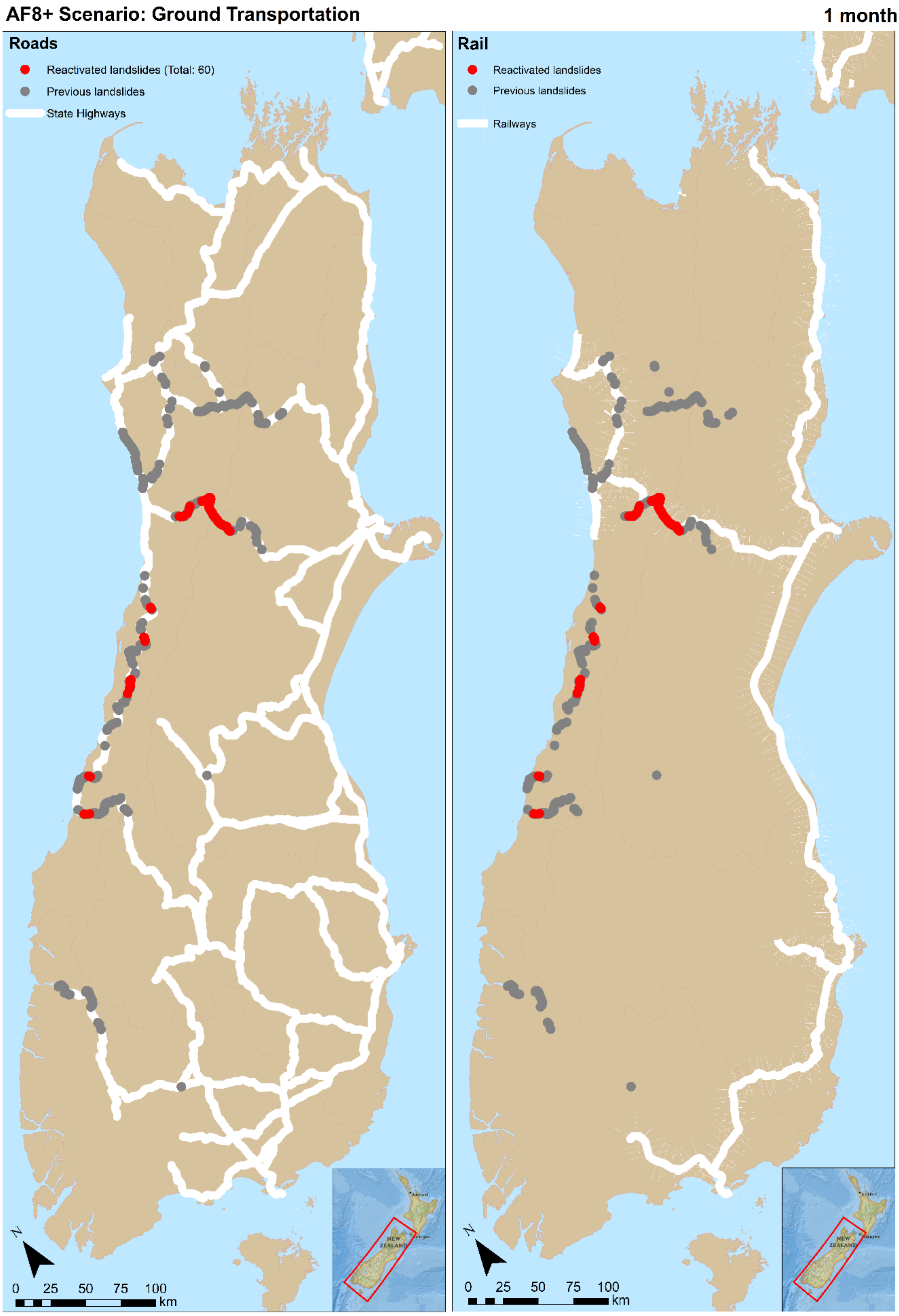

Figure 74. The AF8+ hazard map for State Highways and rail lines (T = 1 month).

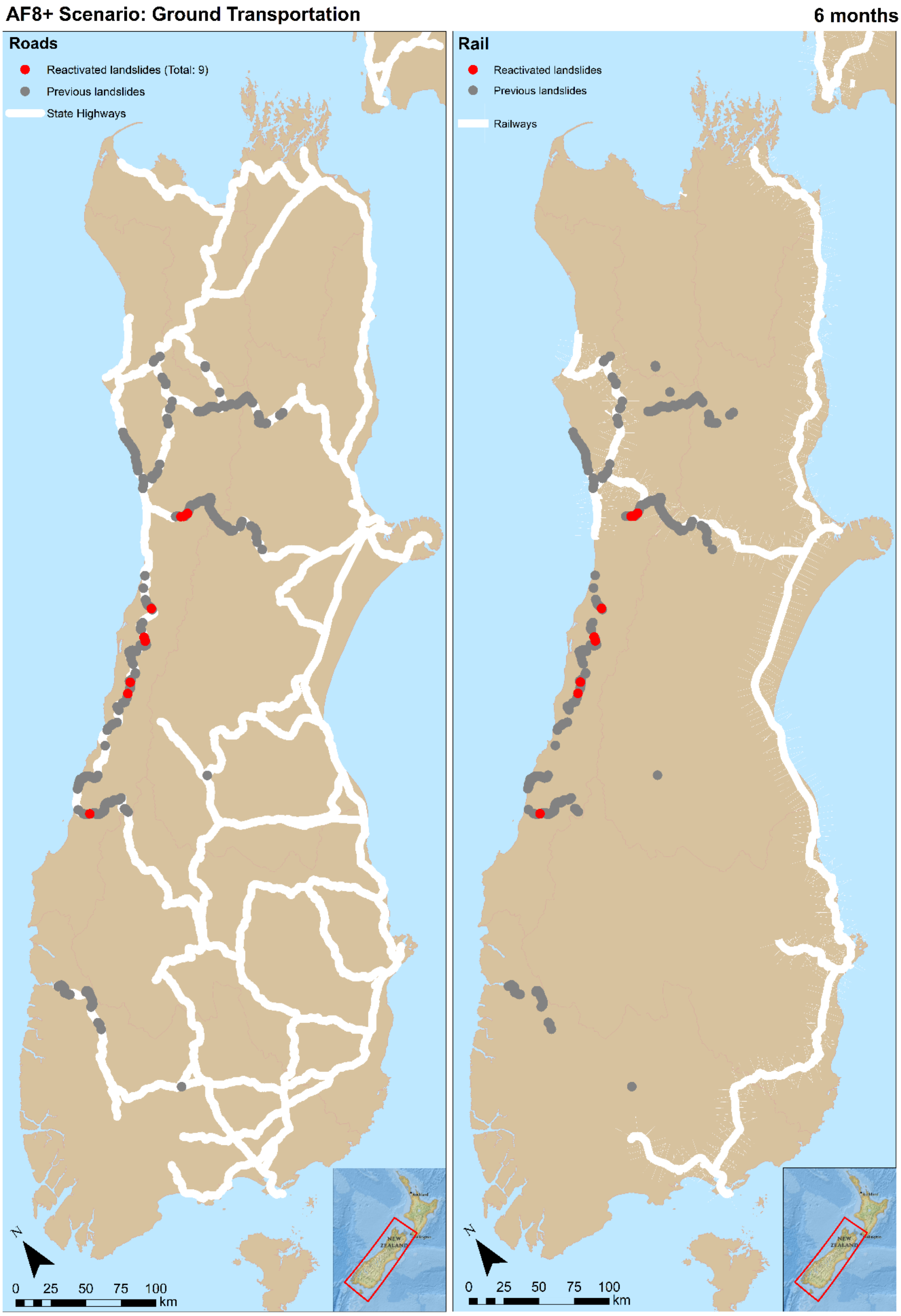

Figure 75. The AF8+ hazard map for State Highways and rail lines (T = 6 months).

Figure 76. The AF8+ hazard map for State Highways and rail lines (T = 1 year).

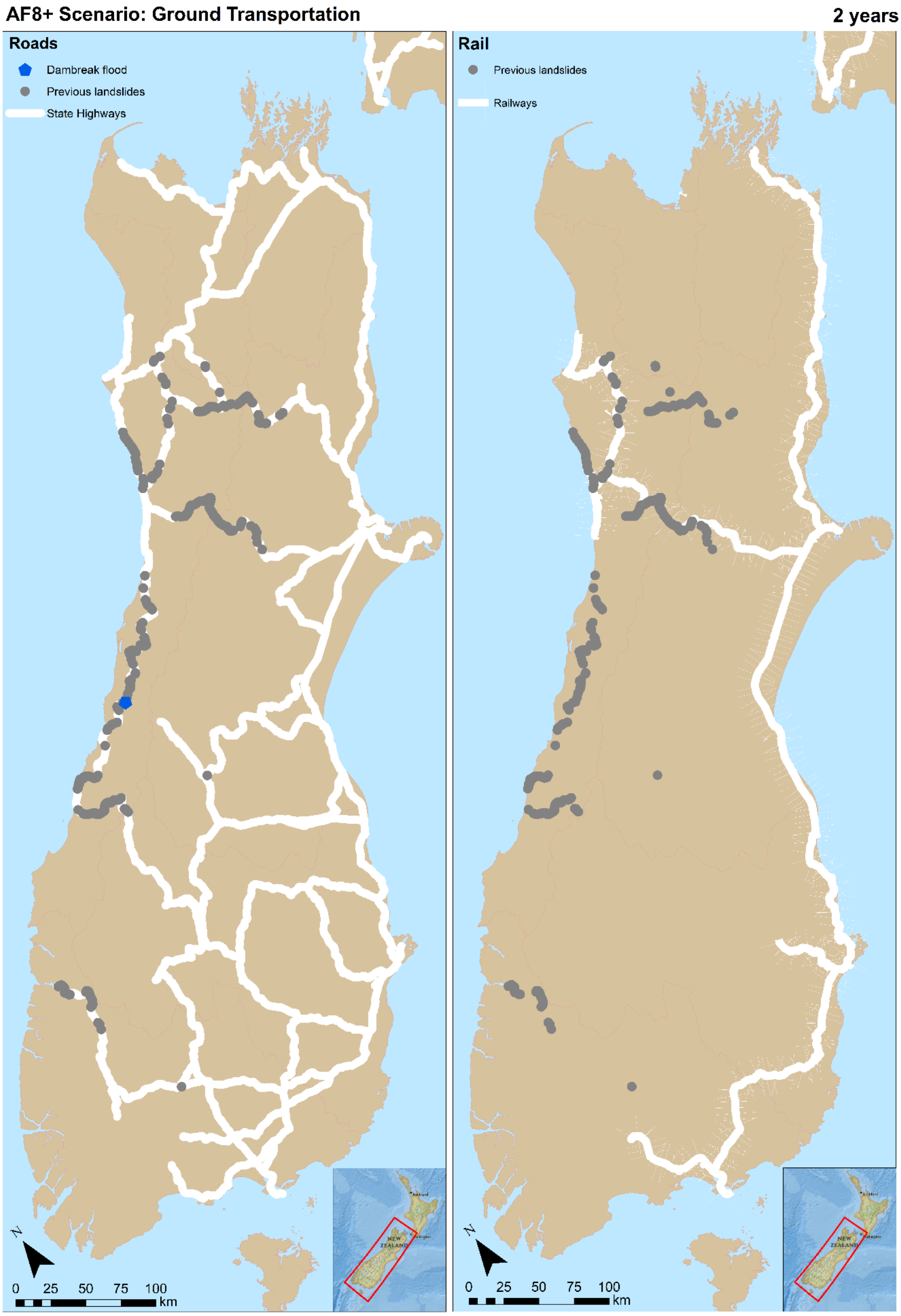

Figure 77. The AF8+ hazard map for State Highways and rail lines (T = 2 years).

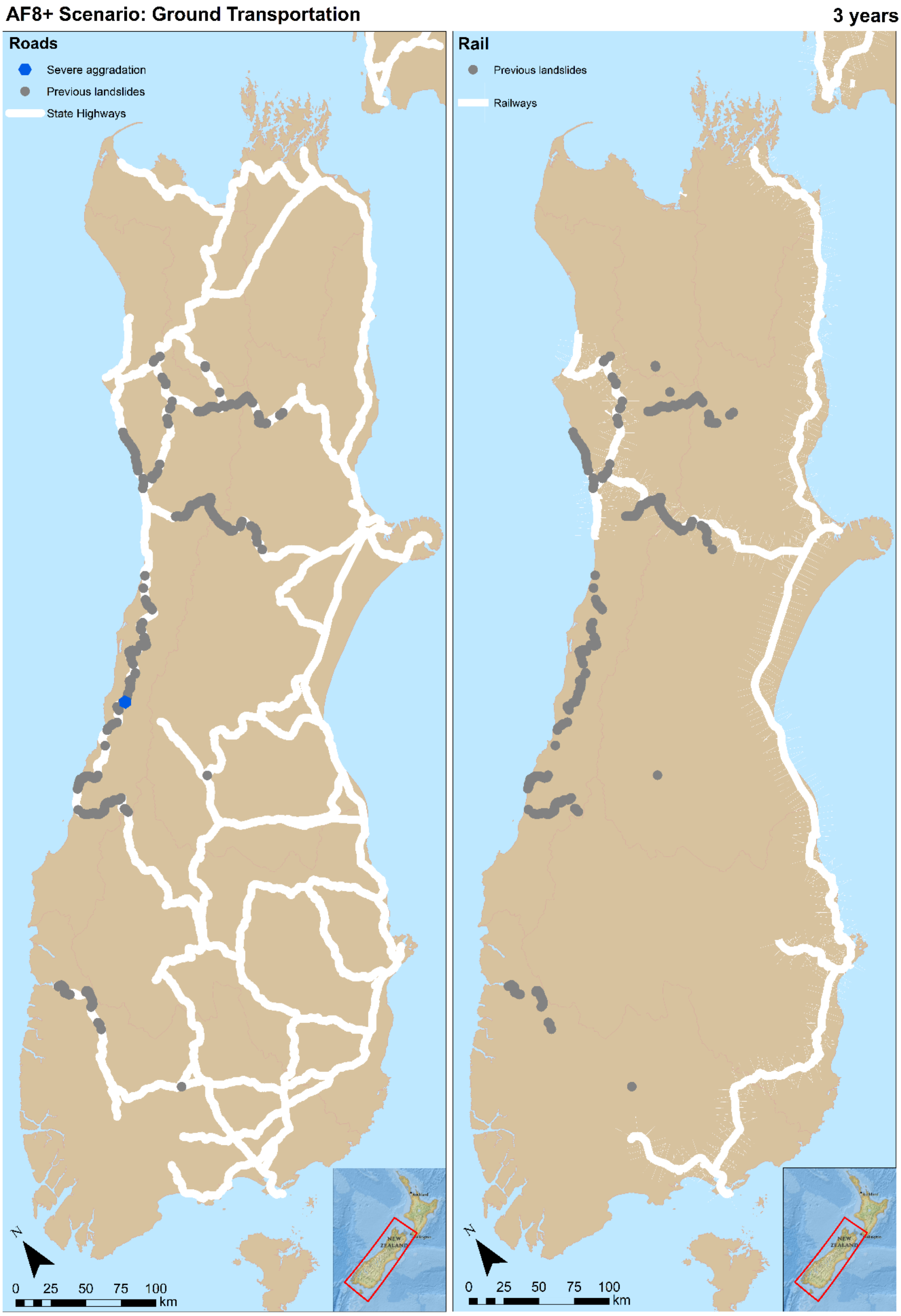

Figure 78. The AF8+ hazard map for State Highways and rail lines (T = 3 years).

Figure 79. The AF8+ hazard map for State Highways and rail lines (T = 4 years).

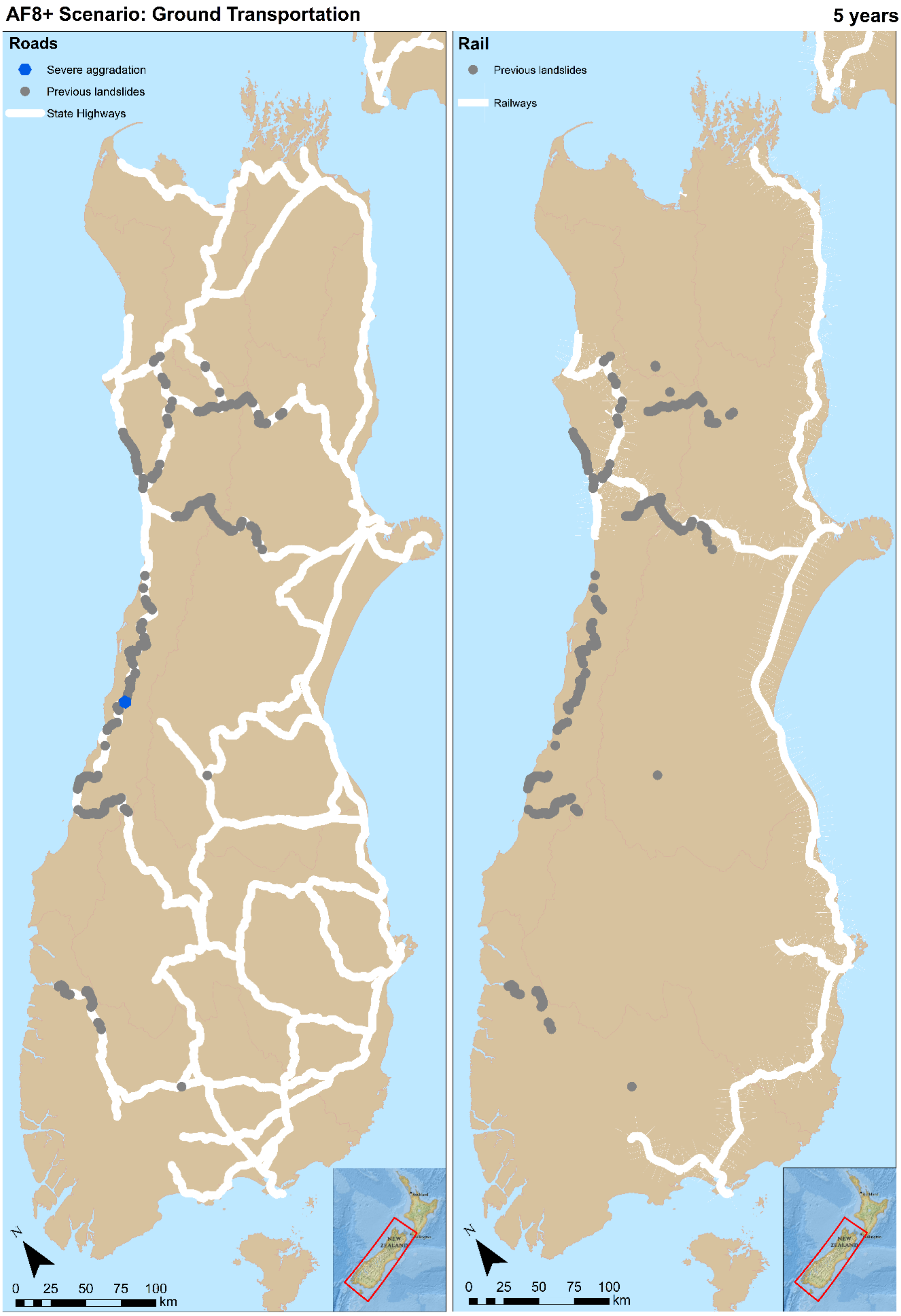

Figure 80. The AF8+ hazard map for State Highways and rail lines (T = 5 years).

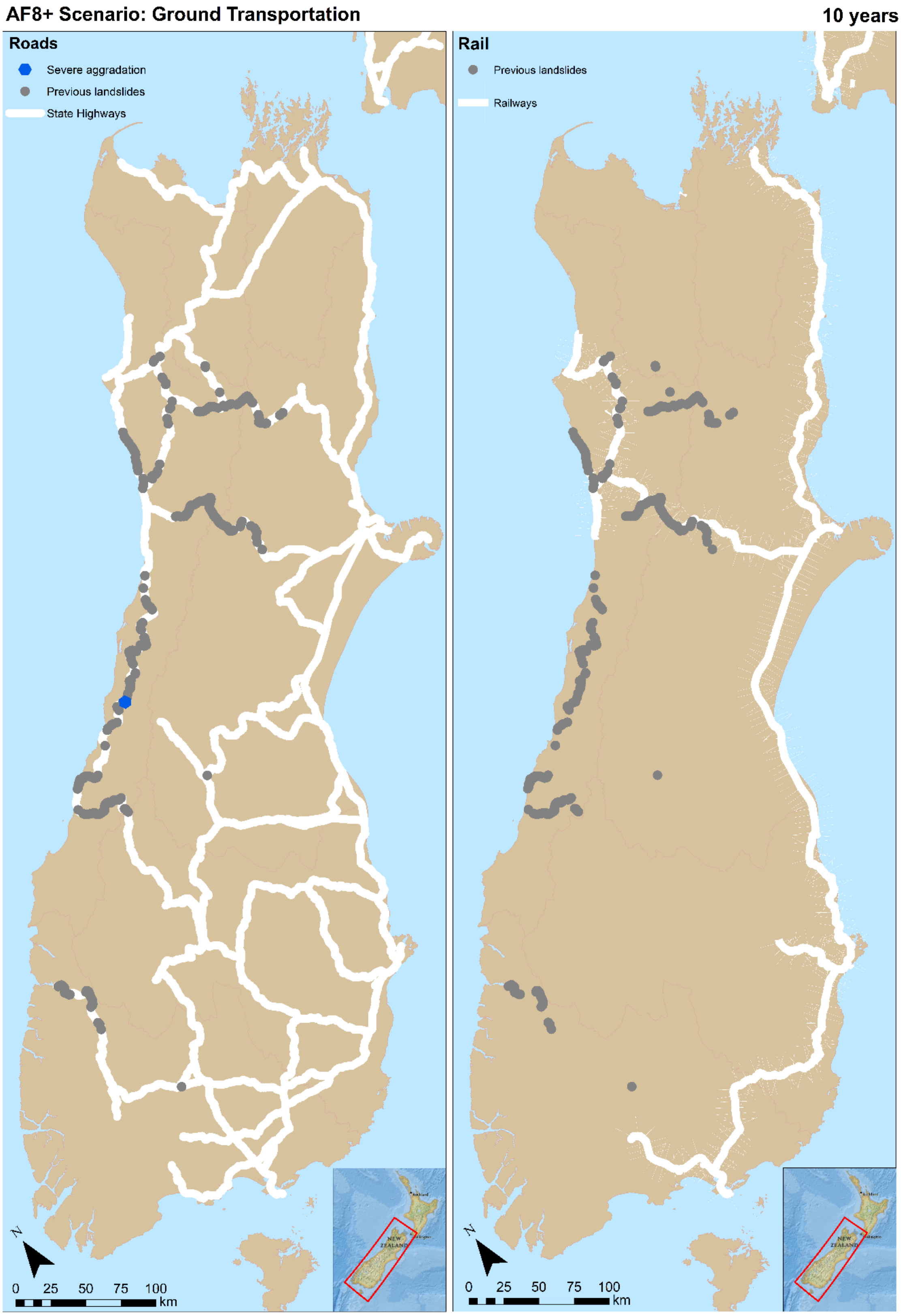

Figure 81. The AF8+ hazard map for State Highways and rail lines (T = 10 years).

Appendix G1. Franz Josef AF8+ earthquake scenario workshop summary

09:00 – 12:30, Saturday 28th October 2017

Medical Centre, Franz Josef

Town resources

Town already has inventory of people/businesses with resources and contact numbers: tarps, chillers, quad bikes, trucks, trailer, fuel, fuel tanker, radios, first aid kits, fire extinguishers, hoses, helicopters, heavy tools, building gear, sat phone, tie downs, containers, language speakers, water, tents, BBQs, ropes, shovels, welding equipment, ladders, other.

People

- Residents = 400
- Tourists = 2000, 150 on ice, 200 in valley

Transport

- 5 helicopters ok
- Have access to heavy moving equipment – diggers, bulldozers, tractors
- Cars/tourist vehicles
- 40 quadbikes
- 27 horses:
    - 17 Horses at South Westland horse treks
    - 5 south of town
    - 5 north of town

Fuel

- LPG (gas cooking): 20,000l (plenty of supply for bbqs)
- JA1: 50,000l = 420 hours flying (and can use this as diesel, so if can refuel elsewhere, solves fuel supply issue for generators)
- Petrol: 15,000l = 20 days
    - 32 generators @ 10l/day = 6400l
    - 9000l remaining:
        - Chainsaws x 20 @ 100l [*need 2 stroke oil/bar lube*]
        - Quadbikes x 40 x 10l/day (8000l already in quads)
- Diesel: 18,000l = 7-10 days supply for generators and earthworks/construction
    - 1 x digger/loader = 150l/day
    - 1 x bulldozer = 300l/day
    - 1 x tractor = 40l/day
    - TOTAL = 4900l/day = 7 days
    - Generators = 20 x 30l = 3600l
    - Vehicles = 20 = 4400l

- Jetfuel = 50,000l x 400 hours flight

Power

- 32 generators:
  - 7 generators in town
  - 13 north of town
  - 12 south of town
- Potential for hydro power supply

Comms

- 3 satellite phones
- VHF radio to north and south

Food

- 4 days for tourists (comfortable)
- 2 weeks for most locals

Water

- Tanks at the top of the town = 100,000l = 20 days (without rain)

Waste water

- Not working, will build long drops

Medical supplies

- 48 hours triage supplies

Evacuations

- Evacuate injured as highest priority
- Goal: evacuate all tourists within 7 days
- 3rd priority: evacuate everyone else from town who wants to leave
- Back-load essential supplies, including medical

Infrastructure expectations

- Expecting to be without road and mains power for at least 6 months
- Expecting immediate satellite comms, cell within a week

Future actions

- Need full inventory of medication needs – priority for stocking, and preparedness for mass casualties event
- Need phone numbers to go with comms. “List of sat phone numbers”. “Contact numbers for neigbouring towns (Okarito, Fox, Whataroa)”. “Contact numbers of local volunteers – first aid responders (mobile coverage could be ok)”
- Language cards/”Multi-lingual placards for information on general welfare/comms”
- User-friendly status codes for Civil Defence (St John – injured, deceased, etc)
- Would be good to also focus on other towns (not just Franz Josef)
- Enquire about VHF and Sat Phones in Okario
- “Info boards around town updating on current water supplies/extra info & updated info”
- “Regular commitment to scenario training – twice year?”
- Consider “dealing with media or potential reporter in town”
- “Resources: Note books, pens, note pads”
- Consider “drone technology”.

Notes relating to workshop

- Demand from tourists wasn’t discussed much
- Would be good to run a workshop drip-feeding info into scenario. “More detailed scenario plot with timed injects – this would test our response more”

Appendix G2. Westpower AF8+ earthquake scenario workshop summary

10:00 – 15:30, Monday 30th October 2017

Ashley Hotel, Greymouth

Scenario response

- This scenario will be quite different from previous events Westpower has had to deal with; won't be like wind-storm where they ramp up their response. This will have no warning AND key staff may be at home or need to be getting home to sort their home situation out (staff welfare).
- Lots of lessons from cyclone Eta, where there was a cascade failure, with 12 poles down:
  - Whataroa farmers looked after themselves, transporting a generator around their farms.
  - 2-8 days to restore 30 poles but pressure was off as local generator provided power.
- There are 2 distinct time periods:
  1. Working out damage and restoration difficulties are highly uncertain for this scenario (time of year has a really important influence on the impact & early recovery).
  2. Restoration times far easier to estimate

1. *Set up EMT*
   - Assuming 2-3 people getting into Emergency Management Team (EMT) on the first day.
   - Need team of people to set up (1-2 days) and maintain EMT:
     - Fuel generator can provide 2-3 days power (lights, radio, comms)
     - To source:
       - Food
       - Water supply
       - Toilets (which will also need servicing)
   - *CDEM:* Group Emergency Operation Centre (EOC) will be gathering data and sharing info on other lifelines. Focus on transport links and telecom repeaters for SCAPA (battery & solo).
2. *Recon all assets*
   - Recon flight (to record video of asset damage) to be led by West Coast CDEM (assumption: CDEM will obtain helicopter or light aircraft for recon on Day 1 or 2 - Medical/welfare will be priority for air resources, but lifelines will also be prioritised). Preferable to drone due to airspace management and distance needing to be assessed.

  - Recon 1: Greymouth to Hokitika for GXPs
  - Recon 2: Whataroa to Hokitika for sub-transmission.
- Westpower can capture GPS impact assessment of data online and offline (at present would have to be ground-based assessment only as flight would be too fast). Every line person has access to GPS mapping to note impacts to poles.

3. *General network restoration*
   - Overall priority to restore sub-transmission to Greymouth. South Westland (Hokitika to Franz Josef) wouldn't initially be prioritised
   - Visit Greymouth, Reefton, Arnold, Rapahoe Transpower Grid Exit Point substations (GXPs) first. These will require civil inspections. On the West Coast, West Power owns most GXPs, unlike the rest of the country, where most GXPs are owned by Transpower. This means West Power can repair them without Transpower, but also that West Power does not have the contractor base to draw from to make these repairs.
   - Substations have 24-48 hours of battery back-up. Some sites have solar back-up. If this power runs out, risky to restore substations. Will first be working to get generators to substations. GXPs are the priority. Thereafter, will need site visit for re-fuelling every 48 hours - the generators will provide around 12 hours of power, but will also charge the substation batteries.
   - If the generators are not available, it is better to shut the station down manually, so they can be started up manually later. Requires site access within 24-48 hours.
   - Westpower does not have generators – will need to source these. All sites have the West Coast standard 50 plugs for generators.
   - Major substations = 48 hours battery back-up
   - Remote substations = 24-48 hours battery back up
   - Batteries are replaced through an annual replacement strategy. If substation battery back-ups fail, car/van batteries can be used, so do not need replacement back-up battery stock.
4. *Transpower supply restoration*
   - Westpower really sceptical about Transpower restoration so quickly. Scenario changed: Transpower only gets power to Reefton by Day 5, Dobson and Greymouth by Day 10.
   - If Transpower supply weeks to months disrupted, Westpower would focus on restoring sub-transmission between power stations.
   - If Transpower was restored from north within days/weeks then the focus would be on restoring northern feed and gradually restoring network southwards.
   - So, helicopter recon really key.

- In this scenario, Westpower trying to restore both.

5. *Power station restoration*
    - Arnold (Lake Brunner) can black start but uncertain it would survive – assumed severely damaged.
    - Dillmans (Kumara) expected to survive but cannot black start. Also cannot supply locally alone as it does not have required frequency governor to maintain stability of the grid at 50Hz.
    - Kaniere Forks and McKays Creek (Hokitika) offer useful generation but again have no frequency governor, so cannot be used alone.
    - Amythyst and Wahapo considered key for power supply without Transpower network. Need one of these power stations for a black start in the West Coast region:
        - Amythyst HEP (Harihari) has black start option, as has speed governor, (note: located close to fault, potential for damage/blocking of water supply).
        - Wahapo HEP (Lake Wahapo) can black start and can be used to start running island network. Used in Cyclone Eta has 6 days' worth of water (note: probably inaccessible due to Mount Hercules (but can set up isolated supply for Franz Josef and Whataroa), potential for damage by lake landslide).
    - Black start would happen post inspectors and getting sub transmission grid back up and useable.
    - Sub-transmission (33kV) is most useful for allowing and connecting "island grids".
    - Feeling was that stations would be 1-2 weeks before getting going

6. *Sub-transmission restoration*
    - Top/first priority would be to get sub-transmission, so would initially ignore distribution except to critical sites, such as Greymouth hospital. "Many areas aren't going to have distribution networks available for months". Priority: sub-transmission between Hari Hari and Hokitika (then Kumara), to enable more generation (then Greymouth). Once have this reliable backbone, won't be reliant on Transpower - Hokitika and Greymouth can be fed on the isolated grid.
    - PRIORITY ROADS: Hari Hari to Inangahua (for restorations and substations)
    - Tourist areas least of Westpower's worries due to evacuation focus.
    - If poles aren't broken, it is pretty easy to get overhead lines.
    - Currently have 70-80 poles (67 10.6m poles) for sub-transmission. For this event would need more poles than current stockpile. Wouldn't consider adding more poles to the reserve stock (at present this is a 2 year "normal use" stockpile so they don't want to add more). Potential to use trees (unlikely). More likely would scavenge

poles from lines that currently provide redundancy or from towns currently without distributed power supply.

- Also require cross arms and other heavy materials to be transported in (too heavy to be airlifted).
- Hari Hari is the main, and southernmost, depot: 6 poles on site. Other depots in Hokitika, Greymouth and Reefton.
- Need 20-30 ton diggers to straighten poles (will be tough). Earthmoving gear would be commandeered.
- Fuel will be a major bottleneck.
- Existing crews are spread out across West Coast (including a few crews between Hari Hari and Franz Josef), so Westpower should be able to assess and start repairs from almost any point on the network
- Would also be huge need to get external crews, who also need to provide their own equipment, vans, etc. Need road access. Conscious that other South Island crews may be saturated/exhausted, so may need North Island/overseas crews for this.
- Supply chain of supplies will be major issue: really will need barge or amphibious access bulk supplies (i.e. poles and bulk fuel) into West Coast.

- *General strategy:*
    - (Assuming that start at Amethyst with no TP feed in North):
        - Amethyst (Hari Hari) to Hokitika = 1 week (if can get crane and resources)
        - Amethyst to Greymouth = 2 weeks
    - (Assuming Transpower restore to north)
        - Reefton = Day 5
        - Reefton to Greymouth = Day 10

<u>Level-of-service through time</u>

Up to 6 months: Response

Main drivers influencing this estimation are demand & limits of network. Assuming no crew limitations, etc.

1 week

- Reefton has main line 33kV Transpower feed.
- Greymouth to Hokitika line repaired as much as possible.
- [Most of South Westland already have back-up generators for reliable power supply]

1 month

After one week, without replenishment of supplies and gear (poles, cross arms, fuel etc.), would run out and be unable to continue repairs. The operation would go backwards as substations would run flat and may not be able to be restored. Wide agreement: Barge into Greymouth would be the most useful within 1 week.

Key constraints: manpower, trucks/diggers, poles, other build materials, fuel, access.

- Reefton to Greymouth has one 110kV (Day 10)
- Amethyst restored
- Sub-transmission to Hokitika (Day 14). Hokitika would be under reduce load rules if only supplied by Amythyst HEP.
- Restore Arnold zone substation
- Greymouth Hospital: power restored (between Day 14 and Day 21)
- Aim to get main town centres' power distribution restored
- Expecting severe damage to underground cables in Greymouth and Hokitika (liquefaction) and Franz Josef (fault rupture). 40-50% and 90% of properties in Greymouth and Hokitika are supplied by underground cable, respectively. Will take more than 1 month (from Day 1) to repair. Many underground cables will be bypassed by temporary overhead lines in response.
- Would try to connect Kumura to Hokitika & Greymouth
- Waihapo may be generating, so should be able to supply Franz Josef and potentially Whataroa, but as an island as Mt Hercules & Fox Hills are very hard country
- Farming communities will unfortunately be ignored at this stage (no power restoration to farms)

- [If transmission (110kV) feed between Reefton and Greymouth not restored, Greymouth would fed by 11kV feed at reduced load]

6 months

Fairly confident would have all power restored within 6 months.

- Assumed road to Fox not open. Fox has isolated power. If money no object, would be pushing hard to restore supply to Fox and beyond, but if trying to save money, it's hard to justify investment south of Fox due to low population and a large area.

After 6 months: Recovery

- Underground cable repairs (to remove temporary overhead lines)
- Staff:

  - Asset team: at present (normal), 16 people. Require 40 people (10 x 4-people crews, with at least one current asset team member in each new crew) for assessments and repairs.
  - Logistics team to help with scheduling of repairs.
  - GIS team, etc.
- Westpower has computer network backup on site (and cloud), but will require internet quickly.
- Standby plan is to head to Electricity Ashburton. For this to be possible, require:
  - Fibre link between east and west coast or satellite connection (councils trialling a system for satellite comms which can provide LAN wifi). Radio network already well integrated with SCAPA networks + internet… can operate anywhere in NZ.
- Road network restoration decisions may dictate power restoration decisions
- National Crisis Management Centre (NCMC) decisions may dictate power restoration, especially for tourist towns (e.g. Franz Josef, Fox Glacier) and dairy: immediately drying off the dairy cows for that season would takes a lot of pressure off (stress to cows means milk is off for a season anyway).
- Although not directly, if the West Coast populations change dramatically after this event, the long-term financial stability of Westpower may become a problem long-term.

Future actions

- Key staff must be resilient = can put already identified food/water supplies in trucks (may need more supplies). “Ensure vital staff are prepared at home to get the EMT up running quicker”.
- Plan for EMT set-up pre-event.
- “A resilient data storage and communication platform considering type and usage of data (operation and control) is the main concern for fast restoration.”.
- Ensure well planned response: don’t want all crews out assessing/repairing (due to later fatigue).
- Pre-plan recon flight routes (West Coast CDEM-led).
- Ensure tracked GPS-enabled “full motion video” footage is captured on recon flight.
- Westpower GIS needs to be compatible with CDEM GIS.
- Need good info from Transpower on recovery time for supply to West Coast.
- Consider pre-arranged (drone) travel routes with air traffic control.
- Stocktake and source generators for substations.
- Design remote shut down switch for substations (particularly for minor, not GXP substations).

- Continue South Island power company coordination, and consider coordination with North Island (and international) power companies for post-disaster response. All power companies should also stocktake post-disaster resources (needs).
- Consider planning (including list of resource needs, and where to source from) for barge into Greymouth within 1 week for bulk supplies (power poles, fuel…).
- Consider planning amount of personnel required for repairs, admin, GIS, and other roles.
- Westpower to investigate satellite comms which can provide LAN wifi.
- Westpower very keen to pursue industry resilience rating metrics (commerce commission collaboration)
- There is currently no requirement for supermarkets or petrol stations to have back-up generators, which would be useful
- "Need for more public education around the need to be self-reliant for a long period of time".

Notes relating to workshop

- Would be useful to have two levels of maps. They have different levels of importance so would be good to show this off:
  - 11kV distribution.
  - Sub-transmission network (33kV).
- Need West Coast power stations on map
- Add Mount Hercules to map
- Need to know fuel availability/level of service (as major limitation) for this scenario.
- Need ports levels of services.
- Need telecoms levels of services.
- Suggestion to split 1, 2, 3, 4, 5, 6 months – will likely restore all power between 1 and 6 months.
- Name tags

Appendix G3. Ground Transport AF8+ earthquake scenario workshops summary

Key scenario outcomes

Figure 50 shows the co-created AF8+ scenario post-disaster expected levels of service for the State Highway network at one day, one week, one month, six months, and beyond six months. Key outcomes include:

No ground transport access to the West Coast for weeks.

- Christchurch and Dunedin will likely be the initial foci of response, with no help on the West Coast.
- The overall priority will be to evacuate people from isolated areas using helicopters and boats (Hokitika airport is expected to open for emergency access within a day).

Daytime access via road between Greymouth, Kumara and Hokitika within one week.

- Emergency road access to Hari Hari may be possible at this point, but would not be a priority unless Westpower is attempting to repair Amethyst power station.
- Within one month, there will be rudimentary, emergency-only daytime ground transport access to the West Coast from the east coast of the South Island, including Westport, Greymouth, Hokitika, Kumara and Karmea.

Limited public road access to the West Coast region within six months.

- Access is expected to be restored southwards to Whataroa, and to Franz Josef around 6 months. NZ Transport Agency would aim to keep good progress going on repairing the main routes, and so would not look to open other roads, unless the government made these a priority.

Almost all road access is expected to be restored beyond six months.

- Including access to Milford Sound
- Exceptions include Arthurs Pass, Haast Pass to Franz Josef and the Coast Road between Greymouth and Westport. Restoration of these routes would depend on long-term government priorities.

The rail network west of Springfield may be closed permanently.

- This outcome will depend on government priorities. Without road access (i.e. through Arthur's Pass), the rail cannot be repaired.

Key findings and recommendations

Below is a summary of the AF8+ scenario key findings (numbered), and some recommendations that were discussed in workshops (lettered):

1. Communication strategies after a major South Island earthquake event remain uncertain.
    a. NZ Transport Agency will need to plan post-event communication links with district EOCs in the West Coast region.
    b. West Coast CDEM plans to establish a list of (satellite) phone numbers to call.
    c. Establish protocol of what to do if the satellite phone network is overloaded (with calls and/or internet data transfer) (for example, through West Coast CDEM).
2. Reconnaissance coordination will be required, and has yet to be planned.
    a. Pre-plan and coordinate infrastructure agency reconnaissance flight routes (for example, through the West Coast Lifelines committee).
    b. Communicate key routes for infrastructure agency reconnaissance, so, where suitable, initial response flights can also gather reconnaissance data. Fit initial response helicopters (for people recovery) with GPS-enabled cameras; use GPS-enabled cameras to capture all reconnaissance data.
    c. Pre-arrange for LiDAR and/or satellite imagery to be captured and provided to EOCs after major earthquakes to enable a more efficient response, facilitating immediate assessments of ground movements which can be used to prioritise response.
    d. Use light aircraft to relieve demand on helicopters.
    e. Pre-event, organise post-event data “clearinghouse”.
3. Response coordination to anticipate and address both regional needs and capacity to contribute has yet to occur.
    a. Prioritise fuel planning (fuel is anticipated as a major limitation in this event, with major uncertainties about availability).
    b. Establish community-specific needs (e.g. which communities will require gas for household purposes, and the point at which supplies will be exhausted after isolation).
    c. Establish pre-disaster dialogue around the most useful and effective contributions communities can make to response and recovery operations. Include safety agreements/procedures for “self-helping” after a disaster, and post-disaster Health and Safety response advice.
        i. Discuss and establish the emergency surge capacity of contractors based in the region.
        ii. Train locally-based contractors to repair airports, airfields and local infrastructure (such as water mains) following major events, as opposed to attempting to open State Highways.

   d. Consider and assess the feasibility of adaptive response approaches with relevant authorities.
      i. Collaborate with the Civil Aviation Authority and utilities organisations to repurpose suitable stretches of State Highway into emergency runways after a major earthquake.
      ii. Collaborate with the NZ Navy and freight companies to coordinate the transportation of goods (including bridges) and people to and from the West Coast by sea after a major earthquake disaster.
   e. Pre-identify and provisionally agree areas suitable for dumping, and areas NOT suitable for dumping material (including culturally significant sites).
   f. Engage with the tourism sector and consider impacts on all elements/types of tourist.
4. Pre-disaster assessment of building alternative routes (e.g. Hollyford or Harper Pass' as alternative access to Haast and Otira, respectively) would enable rapid and effective post-disaster assessment comparisons between repairing damaged routes and building alternative routes, helping response and recovery.
   a. NZ Transport Agency Board should design, cost and formally assess alternative post-Alpine Fault earthquake routes pre-disaster.
5. Following the "Kaikōura" earthquake, we have learnt the more road access is opened, the slower repair work becomes.
   a. Discuss response and recovery priorities with community members.
6. It is likely that the level of damage from both the earthquake and subsequent secondary hazards (e.g. landslides, river aggradation) will force consideration of managed retreat of infrastructure services (including the most vulnerable stretches of road), including settlement and business compensation (similar to "red-zoning" following the Canterbury Earthquake Sequence).
   a. Establish a communication strategy for discussing managed retreat with communities, led by Lifelines committees.
7. The West Coast tourism "loop" is vital for tourism operation on the West Coast today.
   a. Discuss short- and long-term recovery strategies for West Coast tourism with community members and businesses.

Workshops

The ground transport workshop was held between 10:00 and 15:00 on Thursday 2nd November 2017, in the NZ Transport Agency offices in Christchurch. The meeting was attended by representatives from NZ Transport Agency, KiwiRail, Canterbury CDEM, the University of Canterbury and the University of Auckland.

The NZ Transport Agency subcontractors workshop was held between 10:00 and 15:00 on Tuesday 5th December 2017, in the Fulton Hogan offices in Greymouth. The meeting was attended by representatives from NZ Transport Agency, Fulton Hogan, MBD Contracting, and the University of Canterbury. This meeting was organised independently by NZ Transport Agency to provide an opportunity to consult with NZ Transport Agency West Coast subcontractors in order to both inform their response to a major earthquake and corroborate or modify the ground transport workshop estimates of road service levels for the AF8+ scenario. NZ Transport Agency decided not to inform new participants of the outcomes from the previous workshop initially, in order to allow the contractors to estimate road outages independently. The outcomes from the first workshop were discussed after the contractors had made their estimates. The results presented in this document reflect this combined assessment.

The meetings began with a PowerPoint presentation to outline the AF8+ scenario. The participants were encouraged to quality assess the scenario, based on their expert understanding of the local geology, which may be different to the current modelling. The participants then co-created the impacts scenario using their expert knowledge of the network fragility.

The main focus of the workshops was to discuss response and recovery strategies for the State Highway and, in the case of the ground transport workshop, KiwiRail networks. Participants were encouraged to take ownership of the workshops, and to use the time as best suited their desired focus. Pre-prepared laminated A0 hazard exposure maps of the State Highway and KiwiRail networks, detailing the AF8+ hazard scenario, were used by participants to describe post-disaster network levels of service through time. Due to time constraints before the ground transport workshop, landslides were only assessed for the State Highways. Analysis has subsequently been run for the rail network, but was not available for this workshop. Participants were aware of this constraint, which was in part addressed through co-creation of the impacts scenario. The proximity of the road network to the rail network in many parts of the South Island was judged to be adequate to assess the impacts and estimate post-disaster service levels through time for the rail network. At the end of the day, a short debriefing exercise was run to summarise key points from the workshop, and highlight areas participants wished to explore (further) in the future.

The response detailed below is the workshops' participants' best-case assessment of what may reasonably be possible if this AF8+ scenario occurred, based on previous experience, and providing a rough order of likely work progression. This work was detailed to outline the reasoning behind prioritisations, which are intended to be discussed (with the opportunity to modify these) with other infrastructure stakeholders and communities, in subsequent workshops. In the event of a real world

Alpine Fault earthquake, if there is less damage, response times may be faster, and if there is greater damage, response times may be longer. The work assumed that SH1, which was damaged in the 2016 “Kaikōura” earthquake, is fully operational at the beginning of the scenario.

Initial response

A national emergency will be declared, meaning that response will be prioritised by the Ministry of Civil Defence & Emergency Management (MCDEM) and regional CDEM Groups. NZ Transport Agency noted they will sit in on the regional EOC (Emergency Operation Centre) but also need communication with district EOCs in the West Coast region, as they do not have the resources to sit in on both.

This response will follow the principles outlined in the National Response Guidelines: life will be the priority. This means that (initially) infrastructure providers will be of secondary importance, as will business needs. Later, CDEM will use industry groups (such as Federated Farmers and Farm Right) to incorporate business needs.

Christchurch and Dunedin will likely be the initial foci of response, with no help on the West Coast. The overall priority will be to evacuate people from isolated areas using helicopters and boats:

- The event will be of international significance: military partners will offer assistance, which will however probably take more than one week to arrive.
- Milford Sound, Jacksons Bay and possibly other parts of the West Coast may need to be evacuated by boats. Depending on the weather at the time, this could be extremely difficult. Co-seismic hazards resulting from aftershocks also present a substantial risk in Milford Sound.

Most communication on the West Coast will be through satellite phones. This will facilitate communication between Greymouth, Hokitika, Murchison and Franz Josef. Other possible communication links include: NZ Transport Agency, which has radios; KiwiRail, which has a radio communication network which follows the rail corridor and will likely keep going for 72 hours, allowing communication between Westport and Greymouth; the fire service, which has radios; the Department of Conservation (DOC) which has radios; and it is anticipated the military could provide communications if required.

Up to 1 day

NZ Transport Agency and KiwiRail do not anticipate to necessarily have helicopter access immediately (for reconnaissance), however, light planes could be used instead. Flights will be subject to weather conditions, which may slow reconnaissance and response. Reconnaissance would be prioritised for SH7, SH65 and SH69 to lower Buller. It will be critical to identify which structures are broken through the response, as this will affect the whole response. KiwiRail anticipates the need to be using helicopters to recover people on their network.

The day will mostly be spent with staff checking homes and families, assessing resources (including the location of trucks), and undertaking reconnaissance. NZ Transport Agency will also be considering rotation of staff to ensure a consistent approach and points of contact can be maintained through the response. If time is available, priorities would be to help with the reopening of airports and airfields (mending runways, opening as much as possible, even if just for emergency access – i.e. Hercules aircraft), and opening main routes which have low levels of damage.

The Ahaura bridge is due for replacement in the next 5 years, and is currently thought to be highly susceptible to damage. It was decided that the bridge was destroyed in the scenario, but it was anticipated that the river could be forded along an alternative local road for emergency access when reached. Additionally, more landslides than detailed in the scenario were expected in the Upper Buller Gorge and on the northern section of the Coast road. This was factored into service level estimates.

Key points

- Helicopters will be required to evacuate people from the rail network, as well as more generally throughout the South Island.
- No road access to West Coast region and Milford Sound.
    - No road access from east coast beyond Murchison, Hanmer Springs, Springfield, Lake Hawea and Te Anau.
- Reconnaissance prioritised between Murchison, Westport, Hokitika and Hanmer Springs.
- The rail network west of Springfield would be closed for months, if not permanently. It is anticipated this would come down to a government decision. Without road access, the rail cannot be repaired, and even with access, each bridge repair would take months.
- Hokitika airport open for emergency access (i.e. Hercules and smaller aircraft).

1 day to 1 week

Fuel was quickly noted as critical, and a potential major limiting factor in response, both nationally for reconnaissance, as well as regionally for network repairs. In "peacetime", fuel is supplied using a "just in time" model; few reserves are kept in areas isolated in this scenario. Road access is therefore a major constraint for fuel supply. In particular, getting fuel to major centres (such as Westport, Greymouth and Hokitika) and to fuel response and recovery machinery, is key. Gas supply for communities that depend on it for cooking may also be problematic. The need for and availability of fuel could dictate the whole road response, followed by the need for food, then movement of people.

Road access to Westport may be difficult to achieve for a while, and so may have to rely on shipping for supplies. Emergency road access to Hari Hari may be possible, but would not be a priority unless Westpower believes they can repair Amethyst power station.

NZ Transport Agency notes that where the largest impacts to the population have occurred will likely be where the biggest road response effort will be prioritised, under direction from CDEM. NZ Transport

Agency does not anticipate any works to be limited by workforce availability due to their pool of contractors, however, basic supplies (including food) may be limiting factors. Overall, Health and Safety will be the main concern. Both NZ Transport Agency and subcontractors noted they anticipate taking greater risks after a major earthquake. Health and Safety is also a financial concern. Identification of "no-go" areas through reconnaissance helps with this, but the situation can change rapidly. Ongoing aftershocks and landslides may limit response, particularly in mountainous areas, such as the passes into the West Coast.

The major advantage with this event compared to the "Kaikōura" earthquake is that in many places on the West Coast, roads/tracks will be able to go around landslides, as the road is not right on the coast. NZ Transport Agency anticipates this will allow emergency access to be restored at a faster pace than in the "Kaikōura" earthquake.

Given a number of recent upgrade works, and the performance of bridges in the 2016 "Kaikōura" and 2010/2011 Canterbury Earthquake Sequences (see Palermo et al., 2017), NZ Transport Agency does not anticipate unmanageable bridge damage. Where bridges are damaged, NZ Transport Agency has a stock of thirty 100 ft Bailey bridges in Christchurch. Bridges are not stored on the West Coast (any longer) because they are more likely to rust away next to the sea. The major constraint with Bailey bridges also tends to be preparing the groundwork, which takes between 5 days (if building on existing abutments) and 2 weeks. It is anticipated that this preparation time is long enough for NZ Transport Agency to transport bridges to site, likely along roads opened for emergency access. However, West Coast contractors raised concerns that not storing bridges in the West Coast means the region is reliant on the bridges being transported through the passes. This may slow recovery because passes may still be closed when bridges are required within the West Coast region. A solution that may be able to be explored is shipping bridges to Greymouth.

Locally-based contractors will be advised to continue to work to open airports and airfields, as well as to address local roads, water mains, and other local services, as they will make far slower progress on the State Highways than the main response teams (with full resources) but could substantially progress social infrastructure, which will also be more important in the short term.

It is also anticipated that isolated communities will start to self-respond, moving to restore access between settlements, especially where four wheel drives and earth-moving machinery are common.

It may be practical to use State Highways as runways in some locations. This will require conversations with the Civil Aviation Authority and utilities which may need to be removed to enable this (e.g. power poles).

Key points

- No road access to West Coast region and Milford Sound:
    - Daytime access between Greymouth, Hokitika and Kumara. Daytime access is anticipated to be similar to that used following the Kaikōura earthquake, with speed restrictions.

  - Emergency access possible to Hari Hari for electricity repairs.
  - Started work on SH6 to Lower Buller, SH65, SH69 and SH7.
  - On safety grounds, Mount Hercules and the Fox Hills are closed.
  - Because Selwyn District Council plan to evacuate Arthurs Pass village (by helicopter), NZ Transport Agency will not prioritise access to the village. Access will stop at Springfield (no Porters Pass access).
  - No effort further than Te Anau in Fiordland.
- Reconnaissance continuing to build evidence, now including SH6 Hokitika to Lake Hawea, SH67 and SH67A.

1 week to 1 month

Using reconnaissance information and speed of restoration, NZ Transport Agency would swiftly decide which route to prioritise into West Coast: SH6/65 or SH7. Within a month, it is anticipated there will be a rudimentary road open in the daytime along one of these routes, connecting the West Coast to the rest of the South Island. This route would then be focussed on. This would allow fuel to be brought into the West Coast and any remaining tourists and people who wished to leave to be evacuated. The network will remain closed except for emergency access.

Emergency access to Westport will be restored, but otherwise, NZ Transport Agency would prefer to focus on improving access along the emergency routes to two-wheel drive standards, rather than opening up new routes. It may be more beneficial to provide locals with fuel to open up access south of Hari Hari, rather than NZ Transport Agency to resource this.

Diggers will be required for (almost) every river crossing to address river aggradation. It is anticipated a couple of hours work a day at each site will be required to maintain road access.

With more assessments completed, there will be more certainty, allowing longer term decisions to be considered (and perhaps taken) on routes such as the Otira Highway, Haast Pass, and Coast Road (Greymouth to Westport). In this scenario, NZ Transport Agency anticipate the Coast Road collapsed into the sea (the road is built on side-cast material). The possible repair of this road will take a long time, especially given environmental considerations that will need to be accounted for (i.e. not bulldozing loose material into the sea).

Key points

- Emergency access to the West Coast from the east, through SH7:
  - Westport, Greymouth, Hokitika, Kumara, and Karamea have emergency access. Response focus is to increase the level of access to Reefton, Westport, Greymouth, and Hokitika.
- Arthurs Pass, Haast Pass to Franz Josef, SH94 between Te Anau and Milford Sound, and the Coast Road between Greymouth and Westport remain closed.

- Tourism, dairy and ski industries are expected to suffer.
- Expecting a response alliance similar to NCTIR (North Canterbury Transport Infrastructure Recovery alliance) and CERA (Canterbury Earthquake Recovery Authority) to be in place by now. Response camps (similar to NCTIR) may be needed, but if the response is more spread out across the West Coast, these may not be necessary.

1 month to 6 months

Access is expected to be restored southwards to Whataroa within six months. NZ Transport Agency would be working to open road access to Franz Josef, but would aim to not open any further roads, to keep good progress going on repairing the main routes. Response is also likely to be peeled back on the West Coast after the critical response period, as additional resources brought into the West Coast return to address the longer-term repair needs of other parts of the country.

Road access will be very restricted, though residents will be allowed some sort of access. “Convoys” may be run. These will likely be run in the form of a highly-monitored network, with NZ Transport Agency/contractor vehicles on hand to help if vehicles get stuck. Access will be permitted along the route, but with decreased speed limits, high levels of network monitoring and only open for 1-2 days a week for a few hours each day. Very special arrangements may be possible with major industry such as Westland Milk Products, such as access every other day to transport milk in and out of the West Coast.

NZ Transport Agency will make a decision about how far to push into Arthurs Pass. This will be guided by National Response Guidelines, and driven by CDEM – while it may be possible to proceed, there is a risk of being seen to be opening a road for ski fields whilst survival routes are not completed in the West Coast region.

NZ Transport Agency is expecting to implement short-term solutions to ensure access to Westland. For example, through ford access where bridges are damaged. Due to severe aggradation, road damage and low populations, it is anticipated there will be no long-term access to townships including Fox Glacier and Haast. For these locations, it is expected the population will be offered compensation similar to red-zoning, with the exception that if they wish to remain where they are without road access, this could be possible (of note, is that Haast did not have road access until 60 years ago).

Key points

- Daytime road access to West Coast, up to Karamea and Whataroa.
- Working to open road to Franz Josef.
- Some settlements may no longer be viable (at least in terms of providing infrastructure services). Compensation options (along the lines of red-zoning) will need to be considered.

Beyond 6 months

Transport operators would now be working to long-term Government priorities. Given the AF8+ scenario (which has no landslide reactivations on the SH94), it was anticipated road access to Milford Sound would be reopened, and long-term decisions made as to whether to reopen Arthurs Pass and access to Haast. Fox Glacier and beyond is not expected to have access for at least 10 years, especially due to ongoing river aggradation. NZ Transport Agency believes these efforts would be of lowest priority, with a likely decision that access to the West Coast would remain only from the North for the foreseeable future. Other possibilities include restoring the existing road network (possibly with private investment, creating a toll road), building an airport at Franz Josef, building a northern rail corridor out of the West Coast region, to supplement reduced road capabilities, and constructing alternative routes (e.g. Hollyford or Harper Pass as alternative access to Haast and Otira, respectively). These projects would likely take 3-5 years to complete.

It is acknowledged that the West Coast tourism "loop" is vital for tourism operation on the West Coast today. Pre-disaster conversations around the restoration of this loop and other possible short- and long-term solutions were noted as potentially very useful.

Key points

- All road access restored, with the exceptions of Arthurs Pass, Haast Pass to Franz Josef, and the Coast Road between Greymouth and Westport.

Future actions: pre-planning opportunities

Response

- NZ Transport Agency noted they will be located in the regional EOC (Emergency Operation Centre) but need communication into district EOCs in the West Coast region, as they do not have the resources to sit in both.
- Communications prioritisation: (satellite) phone numbers to call, and what to do if the satellite phone network is overloaded (with calls and/or internet data transfer).
- Initial response helicopter flights (for people recovery) could be loaded with cameras and be aware of flight paths that would allow them to also gather reconnaissance data. This would save time and helicopters when both are in high demand.
- Pre-planned and coordinated reconnaissance flight routes using GPS-enabled video cameras could be coordinated between infrastructure agencies (for example, through the West Coast Lifelines committee). The use of light aircraft for this purpose would relieve demand on helicopters.
- LiDAR and/or satellite imagery as soon as possible after the earthquake would be of huge benefit and enable a more efficient response, facilitating immediate assessments of ground movements which can be used to prioritise response.
- A coordinated "clearinghouse" for data collected after a disaster is invaluable, and could be organised pre-event.
- Fuel is a major limitation in this event, with major uncertainties about its availabilities. Fuel planning should be a major response planning priority in the near future.
- Recording which communities require gas supply for cooking so this can be prioritised should also be conducted pre-event.
- Surge capacity of contractors who are relied upon in emergency needs greater consideration.
- The ability to transport goods (up to and including Bailey bridges) and people to and from the West Coast via boats, and in particular ports, is one that is often mooted. However, the viability of this is not something that has been assessed. In this workshop, it was anticipated expansion of Greymouth port could be part of recovery enhancements. However, in the West Coast Lifelines Group workshop, this was not thought to be a workable solution.
- Locally-based contractors can be trained to work to repair airports, airfields and local infrastructure (such as water mains) following major events, as opposed to attempting to open State Highways, as they will make far slower progress on the State Highways than the main response teams (with full resources) but could substantially progress local infrastructure, which will also be more important in the short term.
- There are opportunities to educate people around the usefulness of resources they own in a response (including earth-moving machinery). Coincident with this is the need to educate

around safety concerns of "self-helping" (for example, moving to restore access between settlements) following a major earthquake (especially if providing fuel and advising locals to open roads that are not being prioritised at the time).

- It is anticipated that isolated communities will start to self-respond, moving to restore access between settlements, especially where four-wheel drives and earth-moving machinery are available. Pre-disaster conversations around the most useful and effective contributions communities can make would aid response.
- Both NZ Transport Agency and subcontractors noted they anticipate taking greater risks after a major earthquake. Post-disaster Health and Safety is a "grey area" that warrants pre-disaster investigation. Health and Safety is also a financial concern.
- Pre-disaster resource consents for dumping materials in major events would be useful. Areas for dumping can be pre-identified, and provisionally agreed upon (as can where NOT to dump material, including areas such as culturally significant sites).
- It may be practical to use State Highways as runways in some locations. This will require conversations with the Civil Aviation Authority and utilities which may need to be removed to enable this (e.g. power poles).

Recovery

- A key learning from the reopening of roads following the "Kaikōura" earthquake is that the more road access was opened, the slower the repair work has become. This may factor in decisions being taken around opening roads to different levels of service (e.g. public access, daytime access, number of days open, etc). This is a key point to consider when discussing response and recovery priorities with community members.
- Managed retreat of infrastructure services, and what this means for settlement and business compensation (along the lines of red-zoning) is a major future consideration.
    - NZ Transport Agency is keen for a communication strategy around this issue with communities, led by Lifelines committees.
- It is acknowledged that the West Coast tourism "loop" is vital for tourism operation on the West Coast today. Pre-disaster conversations around the restoration of this loop and other possible short- and long-term solutions were noted as potentially very useful.
- Design, costing and assessment (by NZ Transport Agency board) of alternative routes pre-disaster. This would allow post-disaster assessment comparisons between repairing damaged routes and building alternative routes (including the e.g. Hollyford or Harper Pass' as alternative access to Haast and Otira, respectively).

Other feedback

- More landslides than detailed in the scenario were expected in the Upper Buller Gorge and on the northern section of the Coast road. Further investigation in the modelling of this area may be useful.
- The lack of landslides along the critical link between Hokitika and Greymouth meant NZ Transport Agency suggested it might be worth improving the resilience of this route to ensure it will stay open. This section of road remaining open would help response following a major earthquake.
- “Need to consider how to engage with tourism sector and impacts on all elements/types of tourist”
- “Work with utilities for interdependencies”
- “Need to engage more with Agency staff with knowledge of central Otago and Milford access issues and options”

- “Liked the focus on 1 day, 1 week, 1 month, 1 year, not just initial response – “long term thinking””
    - Greater focus is needed on recovery planning (almost all resilience planning is currently focussed on readiness and response).
- “Liked workshop focus on communities and people, not just numbers, roads, etc”

Appendix G4. West Coast Lifelines AF8+ earthquake scenario workshop summary

13:00 – 16:00, Tuesday 21st November 2017

Westland Milk Products, Hokitika

Carousel Exercise

Black: Power& CDEM = Westpower, Buller Energy, CDEM, 3 waters

Green: Roading = Westland Milk, NZ Transport Agency, Fulton Hogan

Blue: Civil Servants = West Coast Lifelines/CDEM, MCDEM

Post-earthquake expectations for recovery

Require:

- Road access
- Fuel
- Communications
- Building materials
- Transpower (important for electricity):
    - communications
    - their status
- Physical resources – staff, food, Fast Moving Consumer Goods
- "3" Waters
- Reconnaissance flights for situational overview (NZTA key post-Kaikoura lesson was the need to combine reconnaissance flights)
- Reopening/status of institutions (schools, etc)
- Medical facilities and capability
- Welfare – e.g. Temporary settlements, evacuation centres?
- Insurance [added later – need more discussion at senior level]
- Funding – Especially local council [added later – need more discussion at senior level]
    - What is available may only be suitable for smaller event (government grants and business support)
- Rural community expectation:
    - Milk collection
    - Logistical support (isolation)
    - Re-establishing tourism (rural)
- Business continuity ASAP – "Back in Business" (important: gave examples of schools, eg St Margaret's)
    - Government grant (business)

- Support from Central Government – recovery planning
- Fuel/Food/Resources – essentials < 7 days
- Tourists
    - Managing
    - Feeding/Welfare – more applicable to response perhaps
    - Evacuation
- Young people's welfare – education resumes
- Would consider longer-term thinking later

Summary:

- Comms and access focus initially, then re-establishment of mining and existing and new tourism (earthquake-related).
- Comparisons to Kaikōura in thoughts and discussion in requirements of different agencies
- Catering for tourists

Obstacles to recovery

- Resources:
    - Food
    - Contractors
    - Engineers/Geotech
    - Fuel
    - Materials/Bailey Bridges
    - Helicopters/Drones
- Funding & Political will – National or regional priority
- Communications
- People – wellbeing, medical services
- Leadership/Coordination gaps
- Transport links/broken distribution chains
- Lack of power
- "3" waters
- Insufficient/lacking planning
- Weather – discussed in terms of flights and air access particularly
- Aftershocks
- Further landslides – re-blocking roads
- Dam-break risk (natural dams and Kaikoura comparisons)
- Tourists – language difficulties
- Lack of resources held within region

- Over-expectation by the public – should educate (Civil Defence changing from scare tactics to more "touchy-feely" education, also to stockpile 7 days of resources, but this is still optimistic)
- Rural communities vs urban communities preparedness – e.g. thoughts Marlborough & Canterbury may not be as prepared and resilient (tolerance of preparedness) as West Coast. People on West Coast may be more proactive in preparedness – perhaps not so much for business owners and transient populations
- Potential conflict [due to] – in terms of between organisations:
    - Lack of skilled people
    - Competing for limited resources
    - National vs regional vs region [priorities in National event]
    - Managing national transition and new "powers" of people
    - District vs district
    - People vs people
    - Lifeline vs lifeline
- Unsolicited goods [unwanted "aid"] – ties up people, transport, building – BUT may be able to control access to West Coast
- Phycological impacts on people from isolation
    - Example of Canterbury snow storm where loss of comms was the major concern to people
- There is a lack of recovery planning – strong on response planning, but not so much recovery planning
- Landslides

Your contributions

- Try and assess extent of damage to buildings and civil structures
- What risk to life is there from damage structures?
- What is the risk to rescuers from damaged structures?
- Leadership, communication system & process, plans prepared (Civil Defence response)
- Local power generation options (generators; local power stations)
- Westpower and Buller energy are well practiced in dealing with issues
- Proven "control room" operations and emergency management capability
- Local networks/contacts – contractors, etc
- Local knowledge
- Local relationships [this was added and discussed in detail and pre-existing relationships considered highly important for the response]
- Local knowledge
- Local networks

- Local resilience
- Capacity to call on overseas resources (e.g. Fulton Hogan is a Multi-National company, so can internationally support NZTA)
- Plant – big gear – mining
- Mobile comms (milk tankers)
- Water (milk and brewery tankers) [can be used to transport water]
- Local availability & capabilities (west Coast fairly resilient with lots of gear that can be procured)
    - Excavators
    - Helicopters
    - Bulldozers
    - DIY/No 8 wire solutions

Others' contributions

- USAR teams?
- Medical response?
- Outside support
    - Building assessors
    - Supplies
    - People (skilled)
    - Food
    - Fuel
    - Pharmaceuticals
    - Mechanical
    - Medical
    - Parts – power poles, pipes, etc
- Education of unnecessary people
- Government funding
- Communications
- Finance
- Insurance

1. Private sector
2. Other support groups – “student army” “farmy army”
3. International support (see what resources are available around the country, then e.g. Australia):
    - USAR
    - Medical

   - Experts
4. Donations – NZ and other, e.g. "earthquake appeals"
5. UN; Red Cross

- South Island Lines Company Group (4-5 years old alliance) (e.g. West Coast electrical engineers helped in Kaikoura earthquake)
- Links between Christchurch and Wellington – shared agreement to provide spare parts for three waters infrastructure
- AF8 Project
- Transpower
- NZDF & International
- KiwiRail
- Ministry of Health
- MCDEM stressed everything would go through National Crisis Management Centre (NCMC) – tell us what you want, and we'll get it to you.
- Interest in mining resources – not everyone had thought of this
- Need more arrangements beforehand on what resources are there – will change based on contractors there, etc. Could be commandeered.
- People who have gear may not realise how valuable they are – concerns that they may not assist if it does not directly benefit them – can be educated. Pre-existing relationships key
- Some of these discussions can be had at the West Coast Lifelines level
- "If the public can understand better, they will prepare better"
- It's expected the public will be immediately proactive following an event, and will start to save food, etc
- The event is expected to have a worse impact if it occurs in summer, both for the tourism and dairy industries

<u>Level of service maps</u>

- Might be good to introduce greater complexity in levels of service for roads level of service maps – e.g. truck access at 30km/h
- Post-its Buller energy = blue post-its with black pen
- Thin pen on light post-its = 3 waters + Grey District
- CDEM – blue bold pen on light pink post-its

Discussions:

- Emergency power to home medical equipment problem in Christchurch but resolved through battery back-up

- Recent tsunami evac exercise on West Coast “killed 300 people” in the scenario, due to road blockage. Then included public transport but that encountered the same issues. Not clear if people on foot considered
- 300,000 litres of milk required to run processing plant
- Weight of tankers important for road access issues
- Issues with needing access to more milk trucks if rail across South Alps stops [might be good to expand this conversation around brief loss of rail due to fire in 2016]
- If Southern Alps blocked, difficult to get product to Lyttleton port – may lose international contracts to someone else. Unlikely NZ would lose this business, but Westland Milk would be hard hit
- Difficulties shipping unprocessed milk products due to hygiene issues
- Mining also challenge to get products to Lyttelton
- Economics of a new port on West Coast thought to be almost impossible
- Always challenges transporting product in West Coast compared to Canterbury
- Problems getting insurance for lines companies – up 50% for Westpower this year. Can’t get insurance in some parts of the upper South Island
- Fuel supply for everybody important interdependency
- Temporary accommodation for workers may be a problem (has been in Kaikoura, where a “village” took 6 months to set up)
- More work needed particularly on recovery (as opposed to response) on West Coast
- Role of group recovery manager massive, and needs to be pre-designated (this is legislated, so will be addressed shortly)
- Who will manage recovery in three districts also needs consideration
- Roading is the West Coast’s main issue, but exactly how to improve this is not something the Lifelines committee has fully thought through – and might want to in future. Want to tap into National Land Transport Fund.
- Road seen as more important than rail
- “MERIT should incorporate long-term issues and recovery implications”
- NZTA planned projects:
    - Resilience of SH7 (pinchpoints etc)
    - Resilience of SH63
    - Also SH6 (probably)
- Transpower working with Westpower on black starts
- VHF network allows controllers to talk to each other and connect Emergency Operation Centres (EOCs). At hardware rollout/testing stage atm

- Westland Milk relies on overseas contracts to buy milk and remain profitable. They expect to lose these contracts if they cannot supply milk. Westland Milk doesn't have insurance for the loss of an overseas customer. This is the same for mining.
- 1 million tons of coal per year are produced on West Coast
- Westland Milk will be taking decision whether to repair or close the factory with an insurance pay out in this scenario
- In terms of stress on cows, if they manage to remain milking, they could lobby the government about increasing the acceptable level of somatic cell count – which fluctuates throughout the year, increasing towards the end of the season anyway. NZ has among the lowest acceptable levels in the world, so the increase caused by stress to cows may not be significant internationally.
- Currently, 180000l/day arrives via train from Christchurch for processing on the West Coast
- An alternative site is to process milk in Darfield

1 day

- First action of controller will be to lock down all fuel and appoint a fuel manager
- On-farm milk dump
- Pre-planning – supply agreements, MoUs
- Emergency power to home and medical equipment
- What comms available?
- 3 water, staff welfare "KAOS"
- Three water talk to WDC [Westland district council] + BDC [Buller District Council] [from Grey District Council] – what resources have we all got?
- Local staff and local institutions check and support
- Farm animals (e.g. milking)
- Survey network and "make safe" priority tasks
- Farmers generators install and servicing
- Temp accommodation
- Medical evacuation

1 week

- Medical evacuation
- On-farm contingency – milk dump on farm
- Fuel FMCG
- 3 waters pipe materials stocks run out
- Water supply treatment plants rapid assessment
- Water potable critical user hospital CD [Civil Defence] welfare etc

- Network survey complete, temp generators arranged and in place (where possible) [Buller energy?]
- 3 water info, state of network, extent and degree of damage
- Key repairs made (where possible) [Electricity]
- Key repair and reconstruction resources secured [electricity]
- Generators installed and securing key local centres
- Missing persons
- Water potable distribution points (stand pipes) boil water notices
- Generators running fuel issue!
- Initial assessment sewer treatment station and pump stations rapid assessment
- Portaloos – info on garden alternative
- Emergency discharges public warnings
- Emergency housing

1 month

- After 1 week, if can't pick up milk, Westland Milk would advise farmers to dry off their cows. This relates to the minimum amount of milk required to run the factory (300,000 l/day)
- Stock welfare – dry off cows
- "If this event happened tomorrow, Westland Milk would lose 6 months of income: produce 180,000kg/day milk solids, which sell at $6/kg = lost direct gross income of $200 million.
- Generator fuel access
- Initial priority reconstructions <u>done</u>
- Potable water – water residential areas
- Sewer mains CCTV assessments contractor
- Sewer repairs mains
- Housing displaced people

6 months

- Note solid waste demolition material
- Final reconstruction activities done [electricity]
- Need water supply chemicals hold 6 month Lime and Chlonic (?) gas
- Potable water reinstate majority of supply
- Stormwater CCTV assess and prioritise flooding

Beyond 6 months

- Shut down factory – if milk volume remains below trigger level required for factory to function
- Large and long-term reconstruction and/or "new build" projects done [electricity]
- Sewer stormwater continue lower priority areas
- Displaced persons

- Psychosocial support

Key points

- “Rail is essential for long-term survivability”
- “Fuel management”
- “Access by key personnel and plan”
- “Pre-disaster planning is continuous – practice = better implementation”
- “How would our customers respond “look for other suppliers”. Customers need guarantee of supply - reassurance”
- “Impact of a quake on international markets – loss of market and trade, unable to supply”.
- “Reinstate the road access as soon as possible – to truck standards for food and fuel”
- “Tipping points – no fuel, road/rail access”
- “Rail is essential for long-term survivability”

Future actions

- “Do more local lifelines and Civil Defence planning”
- “Need more local resilience”
- “Share BCPs [Business Continuity Plans] or Emergency Management Plans of local businesses/lifelines”
- “Need better understanding of key agreements with service and resource providers i.e. fuel/food/aid”
- “Rubber bladders on off-road dump trucks to bring in fuel”
- “Better education of locals with plant throughout district as to how they can assist the recovery”
- “Pre-disaster emergency management plan and practice scenarios”
- “Fuel supply is a key element that needs more work (planning work)”

Notes relating to workshop

- Would be good to show comparative maps for AF8/Kaikōura/Christchurch earthquake shaking (MMI, PGA for whole of South Island)
- Interest in map showing acceleration in G in particular for buildings
- “Not much discussion heard for airports in particular (although air access issues discussed due to weather, etc)”
- “Recovery prediction, time. The more accurate this is, the more beneficial it would be to business strategy”
- Invite tourism operators to combined workshop
- AF8 response planning needs to highlight need for fuel planning

Appendix G5. Combined Franz Josef/Lifelines AF8+ earthquake scenario workshop summary

10:00 – 15:00, Monday 12th March 2018

Medical Centre, Franz Josef

Limitations

While attendance was unable to be perfect at any of the workshops conducted during this project, due to scheduling conflicts, there were particular difficulties arranging this combined workshop.

It was the intention to hold this combined workshop (between infrastructure stakeholders and Franz Josef community members) shortly after the previous workshops. However, schedules became busy before Christmas in December, and the workshop was then postponed twice in the following months due to two major ex-cyclone events on the West Coast. It remained important to hold the workshop as close as possible to the previous workshops, so the workshop was again rearranged shortly after the second ex-cyclone event, in discussion with infrastructure stakeholders and community members.

Unfortunately, once the combined workshop date was agreed, the Westland District Council debrief for the ex-cyclone events was rearranged to the same date. Representatives from all invited organisations were still able to attend the combined workshop, so the decision was taken, in discussion with infrastructure stakeholders, to proceed with the workshop. While there were benefits to holding the workshop close to the previous workshops and shortly following two major hazard events, due to the Westland District Council debrief, some senior figures who had planned to attend the combined workshop were unable to attend. This will have affected, and in some instances limited, discussions on the day.

The focus of these workshops was to create shared understandings and networks. The workshops relied upon the participants remembered knowledge and a thorough understanding of their, or their organisations', response and recovery strategies, in relation to changing priorities from other stakeholders, which may not have been previously discussed. Accordingly, well-meaning participants may have incorrectly remembered or speculated what actions may occur – particularly when key individuals (who they may normally defer to) were not in attendance. Therefore, the below notes should NOT be taken as fact, but rather as an opportunity to identify where knowledge gaps and uncertainties exist. These can be used to inform future resilience efforts and plans, as part of enhancing the long-term resilience collaborations.

Activity 1

Franz Josef community members and Lifelines stakeholders were split are separately filled out tables with the below headings. Identified issues that placed in differing sections by community members and Lifelines stakeholders are highlighted in yellow.

Appendix G5. Combined Franz Josef/Lifelines AF8+ earthquake scenario workshop summary.

According to community members…	According to Lifelines…
Community members & Lifelines can…	
- Communicate with each other in our communities - Set up welfare centre - Set up information centre - We can hold limited resources	- Set up communications and post-disaster temporary set-ups - Report damage - Liaison CDEM - Set up generators and local facilities - Close roads - Clear material - Minor water repairs/reinstatement
Community members can, but Lifelines can't…	
- Access community knowledge - Access community resources - Act as best we can, as we are not professionals	- Use local access (response) - Organise local emergency services - Use local resources (e.g. generators) - Use controllers network - Ration supplies (fuel, food, water)
Lifelines can, but community members can't…	
- Make power lines safe - Close the roads - Open the roads - Repair water and sewerage (except Okarito for water) - Provide professional assistance - Hold unlimited resources - Declare state of emergency	- Isolate power and connect power - Officially open roads - Treatment plants/all waste water - Bridges - Structural assessment - Connect communications - Provide restoration and access time
Community members & Lifelines can't…	
- Communicate between communities - Foresee what's going to happen	- Work when risks are too high (Lifelines will stand down staff when dark, strong winds, aftershocks) - Open roads without fuel - Control public: Cannot enforce road closures (unless declaration of emergency) - Declare emergency - Immediately restore powerlines (in an extreme event, all lifelines could be out)

Activity 2: What is needed for meaningful recovery, and what happens if you don't get what's needed?

A summary of the answers is provided below. These were prioritised in the workshop, with the "most important" answers placed at the top of the lists below. Bullet pointed answers were not given priority ticks.

1 week

1. Tourists/visitors evacuated.
    - Don't have enough supplies to support non-resident population. Tourists major drain on limited resources.
2. Provision of supplies to last extended period (fuel, food, water, etc).
3. Communication established. Including updates on road and power status', and external reassurance that response is occurring and planning is underway for evacuation and provision of supplies.
4. Response planning. Adequate SIMS structures. Authority figure for chain of command.
    - Duplication of resources/efforts. Disorganised response; chaos. Response keeps falling back onto the same people (who also need to look after their own family, etc).
5. Emergency shelter/housing.
    - Welfare problems, homeless people.
6. Resources pooled and controlled.
7. Professional help (Red Cross; LandSAR): search & rescue and medical assistance for injured.
8. Welfare centre for tourists/visitors.
9. Building repairs.

- Assessing infrastructure condition.
    - Poor/Unreliable response due to poor data.
- Situational awareness of whole region for communities and Lifelines.
- Local roads open, power established, fuel and food supplied.

1 month

1. Regular supply of food, water and fuel
    - No fuel = no work (e.g. repairs and lifeline reinstatement). If progress hasn't started, people will start to leave Franz Josef.
2. Insurance (claims)
3. Business support, long-term recovery planning, including future of Franz Josef.
    - Business failure, putting the community in trouble.
4. Competing with the rest of New Zealand for resources. Political commitment to Franz Josef. National decisions on government priorities.
    - Local, regional and national political arguments

5. Establish alliance for recovery (Government-led infrastructure decisions), access to the rest of New Zealand, access for fault repairs, and plan and timeline for reinstatement of infrastructure. Bailey bridges. Reliable power, communications, drinking water, sewerage and rubbish removal/waste management (debris, personal and medical waste, etc) restored.
    - If no drinking water, need to bring in water. Risk of illness.
    - No bridges, no access, especially during rainfall events.
6. Psycho-social support
    - Psycho-social aspects emotionally intolerable.
7. Medical centre established. Restocked emergency services.
    - Health issues
8. Non-residents (tourists, etc) all evacuated
9. Proper management of resources – food/water/medical supplies (rationing). There are also limited stocks for repairs, which will impact response and recovery.
    - Poor prioritisation = health/welfare problems
10. Craft beer

- Building/structure assessment
    - Welfare (shelter) issues
- Moving to life in new normal
    - Recover or abandon? Need to adjust to new reality.
- Updates on progress
- Public should be looking after themselves

6 months

1. Communicate to appropriate agency or CDEM.
    - Competing with the rest of New Zealand for resources
2. Skilled workforce available
3. Communications
4. Plan for future
    - Economic downturn for region, business closure.
    - Lose volunteers – either leave area or burnt out
5. Welfare and medical, including counselling services.
    - Long-term increase in rates of stress or depression. Untreated medical conditions or injuries.
6. Restricted access to Franz Josef.
    - Lone locals will move away. Lack of employment. Delay in “opening” region and slow recovery.
7. Locals employed in recovery effort

8. Fuel
   - No fuel = no work, no repairs, no power, communication, recovery time longer, difficulties for town/personal lives (cooking, etc).
9. Power, internet/mobile, landline, sewerage, water restored.

- Reinstate tourist industry to greatest extent possible.
  - Long-term future of Franz Josef in doubt.
- All services and community working together to rebuild and plan future. Need community buy-in. Need to work with councils.
- Insurance and services in place for business
  - Will slow response and recovery.
- Consent to rebuild – where's red-zoned?

Over 6 months

1. Rebuilding infrastructure
   - If road isn't reinstated, can't do the other priorities beyond 6 months. Short/medium term, NZ Inc. struggles
2. Jobs and employment
   - Tourism downturn for whole country
3. Counselling services, people affected mentally
   - PTS, increased drug abuse and alcohol, anger and violence etc.
4. Insurance 'how to' help personal and business
   - Loss of income, people not able to leave/get away and relax (holiday from the carnage).
5. Govt. support, new people, adjust to new reality
   - Loss of Franz Josef. Stop the relocation of township.
6. Keep families in Franz Josef. Includes needing to keep schools open.
   - People leaving Franz – less workers, businesses close. People leaving West Coast and even NZ – tourists not wanting to visit.
   - Without schools, families will leave. But it's important families stay for the town to stay open.
7. Acceptance of new normal
   - If there are no signs of recovery at 6 months, divisions may form between community members; between people wanting access to rebuild, and those wanting their money (insurance pay-out) to leave Franz Josef. Resentment and retreat.
8. Fuel
   - Can't do anything or recover

Activity 3: Discussion

Response

- Couldn't fly during the ex-cyclones – reality for reconnaissance.
- Communications were also difficult during the ex-cyclones – an area that remains a weakness (Westpower advised they have a VHF radio in Fox substation which can be used in emergencies).
- For large events, Geotechs need to confirm worksites are safe before Lifelines can start repairs.
- Roads can be closed by Lifelines or the community with good reason, but can't be officially enforced without CDEM declaration of a State of Emergency. The ex-cyclone showed people driving on closed roads slowed repairs (i.e. roads need to be closed to repair powerlines). Communities could organise more people on the ground to man road blocks to help speed the response.
- After a major hazard, the township will need resources in quickly; Franz Josef has limited resources (including medical needs), particularly during peak tourist season. For supplies/resources to be officially rationed a state of emergency must have been declared. However, the community can self-organise rationing of key resources.
- Low resourcing (no. of trained staff) was noted as a major issue (medical, police, fire, etc): professional assistance will be required after major event (e.g. nurse has big area to cover in peacetime, so will not be able to assist everyone during a major event).
    - As a multi-national, Fulton Hogan can pull staff from Australia.
- To get resources and assistance quickly, need to provide situation report quickly: fuel, food, generators. This will help CDEM prioritise where resources need to go (acknowledging communications were difficult during the ex-cyclones).
- A state of emergency cannot be declared only for (e.g.) Franz Josef township, but if the community can't communicate with Hokitika, they can act as if it's been declared.
- Community can set up info boards but sometimes social media says something else – can cause problems.
- NZTA is trying to make NZTA website & telephone only source of info for State Highways, but this doesn't include local roads – opportunity for regional council to link in or provide this info on website.
- Volunteers can only do as well as they can. They are well-meaning, but their knowledge is often quite shallow (CDEM might be able to provide this training?). There may also be issues around who leads post-disaster response in townships (e.g. there are no police in Fox).
- Communicating with tourists can be difficult, especially where there is a language barrier.

Recovery

- The closure of the three Alpine passes in this scenario will mean work to provide road access to the West Coast will progress at a pace that is unlikely to be increased by using more resources.

- The time of year will have an impact on the rate of recovery. More rain will slow the recovery.
- Aftershocks will also affect repair and response progress.

Readiness

- South Island electricity distributors are now meeting regularly.
- The importance of electronic communications for commerce needs to be better considered
- CDEM Group preparing to distribute sat phone directors
- Need to keep updating skills lists etc, as people move to or leave town.

Future work

- ***COMMUNICATE THE WORKSHOPS' OUTCOMES***
    - Communicate to locals, and to Wellington.
    - Explain in Layman's terms, and what they need to do about it.
- It would be useful to do some pre-planning around post-event advocacy to Government
    - Policy assistance, with economic costings
- From a business point of view, knowing likely outage times (as shown in the maps used in the workshop) is very useful for crisis management. It would be good to have these resources communicated (possibly through Lifelines?).
    - List of things businesses can do to prepare for disasters
- Capabilities and training and preparation for response and recovery. Need key prep info to be saturated through the communication channels and more training to upskill local response capabilities. Further workshops/exercises (possibly CDEM-led) which would be useful:
    - Loss of communications
    - Business continuity
    - Business planning
    - Crisis planning
    - Insurance
- List of network weaknesses
- Estimate transient populations
- Effective link between lifelines and community post-disaster assessment? Region/district/local CDEM needs to feed this info up/down.
    - Structure to communicate with lifelines needs to be clearly communicated to community
- Make GIS available to public post-disaster
- Post-disaster H&S grey area – can we open/self-assist. Not grey area – as soon as someone is directed by an agency, H&S applies.
- Newer satellite phones would be useful
- Contractors going through road blocks – should we be registering them in/out of these areas?
- Whose responsibility is resource management? If community how/who organises and rations it?

- Work with Australian Civil Defence. Partnership program.

Activity 4: Workshop feedback

Community members

- Great, very informative. Highlighted some processes that would be helpful. Getting the information out to the public could be problematic
- Great being able to have conversations with "Lifeline" companies/representatives and see from their perspective
- Group involvement or activities always get good engagement
- 3rd workshop been to, best combination of community members and lifelines
- Great getting info from Lifelines especially NZTA, hearing their side of what their plan is in a scenario/real life incident
- Great:
    - Agencies attending. Transit/Fulton Hogan/Westpower/Rob Daniels
    - Short/Long term expectations surrounding road closures. Long term Expectations.
- Workshop was good, would like to see more crisis management planning at a community/business level
- Another useful workshop
- Good to have these sessions and add academic and community views together
- Need to have more key players around the table to get more saturation of info and spread of input
- Civil Defence should not rely so much on volunteers and volunteers' goodwill
- Getting information out to the public. Tourism and local is very important for preparedness. Always going to have people rebel against info.

Lifelines

- Good: conversation after lunch to discuss main concerns
- Improvements: knowledge was not same level by participants - some reading
- Good: Lifelines and community talking together
- Need to deliver message to wider community
- Where to from here. Positive discussion.
- Good: opportunity to hear both sides of the story.
- Always good to get additional input.
- Good open discussion with community.

General

- Workshop timing: key agencies from lifelines and communities may be underrepresented
- Keep smiling 😊